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PROCEEDINGS

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OF

PHILADELPHIA.

ORGANIZED, 1877.

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Yours Truly
James Christie

Elected President January 16th, 1892, for the Fifteenth Year of the Club, A. D. 1892.

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OF THE

ENGINEERS' CLUB OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

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I.

LAND-LOCKED NAVIGATION FROM NEW YORK CITY TO CHARLESTON, S. C.

Compiled by JOHN C. TRAUTWINE, JR., from notes furnished by CAPTAIN SPENCER C. MCCORKLE.

Read October 3, 1891.

AT a meeting of the Club, held April 21, of this year, I had the pleasure of reading, for Captain Spencer C. McCorkle, a paper entitled "Land-locked Navigation from Long Island Sound to the Mississippi River." In that paper, the author urged the great national importance of such a means of communication for light-draught vessels by way of the innumerable bays and inlets of our coast, and quoted General (then President) Grant in support of the assertions that "such a route along our coast would be of great value at all times, and of inestimable value in case of foreign war," and that "Nature has provided the greater part of this route, and the obstacles to be overcome are easily within the skill of the engineers."

The paper referred to dealt chiefly with the southern or western end of the proposed line of "land-locked navigation from Long Island Sound to the Mississippi River," namely, from the mouth of the classic Suwanee River, on the Gulf Coast of the Peninsula of Florida, via St. Mark's, Appalachicola and St. Andrew's Bay, Fla., and Mobile Bay, Ala., to the Mississippi River, near New Orleans, and deferred until a later occasion the consideration of the central portion and of the northern or eastern portion of the route. It is to this latter portion (viz., from New York City to Charleston, S. C.) that I ask your attention this evening. Captain McCorkle has kindly furnished the data which, at his request, I have simply prepared for presentation to the Club.

Briefly outlined, the route from New York City to Charleston would pass through Raritan Bay and up the Raritan River to New Brunswick, N. J.; through the Raritan and Delaware Canal to Bordentown, N. J.; down the Delaware River to Delaware City; through the Delaware and Chesapeake Canal to Chesapeake Bay; down this bay to Norfolk, Va.; from Portsmouth (opposite Norfolk) up Southern River and through the Albemarle and Chesapeake Canal, North Landing River, Currituck Sound, a short canal and the North River, into Albemarle and Pamlico Sounds; and thence through Core Sound to Beaufort and Moorhead City, N. C.; thence by sheltered inlets, on which some work would be required, to Cape Fear River, N. C.; and from this point, by a series of streams and bays and sheltered inlets, aided by canals, existing and contemplated, to Charleston, S. C.

From New York to Beaufort and Moorhead City, N. C., the route is already open to vessels drawing seven feet, except that some little dredging would be required at Piney Point, in Core Sound, between Pamlico Sound and Beaufort.

The "Bight" inside Cape Lookout shoal, near Beaufort, is said by Captain D. A. French, of the Lighthouse tender "Laurel," to be "a splendid harbor with any wind in eighteen feet of water."

From Moorhead City to near Bogue Inlet, twenty-five miles, the least depth shown on the charts is 2.5 feet, but there are much greater intervening depths. From Bogue Inlet to New

River Inlet, fifteen miles, there are channels through sea marsh, but their depth has not yet been ascertained. From New River Inlet, through Old Topsail Inlet to the western end of Myrtle Sound, fifty miles, the route passes through a series of bays and sounds, giving a nearly continuous water passage; but only a few soundings have been made here.

From Myrtle Bay a canal about 2.5 miles long would have to be cut through low ground to the channel of Cape Fear River.

The total distance from Moorhead City to the Cape Fear River by this route would be about 92.5 miles. Being all inside, it would avoid the shifting sand-bars of the North Carolina coast, and the dangerous navigation around Capes Lookout and Fear; and, judging from the success of the Albemarle and Chesapeake Canal, there is every reason to believe that it would remain in permanent and active operation.

From the Cape Fear River at Southport (formerly Smithville), N. C., to Charleston, S. C., there is an outside route of about 125 miles, with 14 feet mean low water over the bar at the port at each end. This was formerly the mail route; and the steamers, although very frail and of small power, were very successful.

The inside route, about 140 miles long, between the same two points, would pass up Elizabeth River to Hickory Point, whence a canal two miles long would have to be cut through swampy land to water communication with Lockwood's Folly, Shallotte Inlet and Little River Inlet. Between Little River Inlet and Morrill's Inlet, a distance of thirty miles, is a low, flat, swampy district, which would have to be specially surveyed, and probably some canaling would be required.

From Morrill's Inlet to Georgetown, S. C., there is water communication. Between Georgetown and Cape Romain River two short canals may be necessary, one of which (the U. S. canal) has been partially, if not fully, constructed.

From Cape Romain River to Long Island, via Bull's Bay and following the creeks, there is water all the way, but some straightening and dredging will doubtless be required. From Long Island to Charleston there is water communication, but the depth is not known.

There alway has been an inland passage between Charleston

and Fernandina. Previous to the building of the railroad from Charleston to Savannah, the Southern mail and passengers were always carried by boat from Charleston to Savannah; and the steamboats, after touching at Savannah, proceeded to Fernandina, etc.

Captain McCorkle holds that the advantages of inland navigation along our whole Atlantic and Gulf coast are of the first importance; and the object of this paper is to bring the matter before the public in a substantial shape. Both the Government and syndicates undertake large surveys that do not promise a tithe of the advantages that would accrue to a large number of the people of these United States from this great water connection.

Appendix A.

A glance at a map of the United States will show that the Atlantic coast from New Jersey to Florida is outlined by long, low islands, sand-banks for the most part, presenting natural barriers to the inroads of the sea. There are considerable intervals, as on the coasts of the Carolinas, where these defenses are lacking, but they extend thousands of miles along the ocean front, and constitute a geographical feature that may eventually be recognized as of prime importance. Between these islands and the mainland are waterways of varied character, sometimes expanding into broad sounds, like Albemarle and Pamlico, and sometimes contracted to narrow, tortuous bayous. These waterways are navigable to a greater extent than has ever been generally understood, though local commerce, especially along the more southerly coasts, has long made them available for light craft that could not venture out to sea. The Government, through the Navy and the Coast Survey, has given a good deal of attention to the matter, but the best knowledge we have has been afforded by the ventures of private enterprise. A current report of a trip made by the steamer City of Jacksonville practically demonstrates the soundness of a claim often made and often disputed that these inside channels can be followed by commercial craft from the St. John's River, in Florida, to Charleston, South Carolina, a distance of 200 miles. The passage was first made by the United States Revenue cutter Morrill, but with such difficulty that it was

doubted if it would ever be attempted again. The City of Jacksonville is a river passenger steamer, plying on the St. John's during the winter season, measuring 175 feet in length, 52 feet beam, and drawing 5 feet. The Morrill draws 9 feet, but there are only one or two points where shallow water constitutes the most serious obstacle, very narrow and crooked passages presenting the greatest difficulty. The trip of the City of Jacksonville proves that steamboat navigation can be established between Charleston and Savannah and the St. John's River by inside lines, and that with comparatively little outlay for straightening channels, cutting off corners and widening straits, these lines can be made safe and practicable for river steamers. This means, also, that they can be used in case of need for gunboats and torpedo craft, affording an interior line of communication along nearly one-third of our Southern Atlantic coast. How much further this interior communication can be extended is a question which the Government should not leave for steamboat captains to answer.—*Evening Telegraph, May 28th*, 1891.

Appendix B.

Senator Pasco, by request, to-day introduced a bill to incorporate the Atlantic, Mexican Gulf and Mississippi Barge Canal Company, and to grant to it the right of way through the lands of the United States. The route of the proposed canal shall be from a point on the Mississippi River at or near New Orleans, through Lakes Borgne and Ponchartrain and over the inland coast waters to a point near St. Mark's, Fla., and thence across that State by the most feasible route to the Atlantic Ocean. A Board of Commissioners is constituted to be vested with the power of constructing the canal, and the capital stock is fixed at 100,000 shares of $100 each.—*From a recent newspaper.*

DISCUSSION.

By J. Foster Crowell.

Read October 3, 1891.

Some years ago I located and built a railroad connecting Norfolk Harbor with Albemarle Sound, and the knowledge thus

gained of the Virginia and North Carolina section of the proposed inland waterway led me at that time, and since, to give some attention to the scheme which is outlined in this paper. I was struck, as all must be, with its extreme simplicity and feasibility, so far at least as the part of the route lying between New York and Beaufort, N. C., is concerned. South of Beaufort my observation did not extend. The recent passage of "The City of Jacksonville" has demonstrated a like feasibility between Charleston, S. C., and the St. John's River in Florida. The only *terra incognita*, as is shown by Capt. McCorkle in the notes under discussion, lies in places between the Cape Fear River and Charleston, and much of that stretch also is known to be suitable. I regret that I received the paper almost too late to permit of such discussion as its importance demands; in the short time that is available I shall confine my remarks to some very brief comments upon the subject of getting this matter before the public and enlisting the action of the Government. In time past I have, as a member of this Club, contended that such action as is contemplated by the proposed resolution memorializing Congress is an entirely proper exercise of the Club's public function; on the other hand, in this particular case, I do not think the resolution as worded carries the weight it should, for the reason that it wears the aspect of an application for indirect benefit to the interests of engineers. That this is very far from being the motive of the disinterested gentlemen who propose the resolution, goes without saying; but I think it is the view the public would take, and the opposing interests make much of. Then, again, the hostility to an inland scheme, extending on from the Florida coast to the Mississippi, is very marked on the part of all the railroad interests, and it does not seem to me to be well to load down the feasible and self-recommendatory part of the project with the less advantageous and more costly features of the part which would be violently opposed. While the ultimate completion to the Gulf of Mexico is a necessary concomitant of a comprehensive scheme, it is nevertheless true that the part lying between New York Bay and the St. John's River is the most important, the most feasible, the least costly per average mile, and would serve a most useful purpose by itself. It may be added that the opening of this

part of the route to navigation would probably be quickly followed, if indeed it were not preceded, by the Florida Ship Canal.*

By Rudolph Hering.

Read October 3, 1891.

I have read the two papers on this subject with much interest. The scheme outlined by Captain McCorkle is entirely practicable, and, from the unusual natural advantages, one that could be carried out at a comparatively small cost when considering the total length of the waterway. The question should be considered from a military and from a commercial point of view. The discussion of the former should be left to the army officers. The commercial aspect requires a consideration of the probable traffic and of the cost of the waterway, from which the question, Will it pay? can be answered. Such a waterway would be used mainly for local traffic, concentrating at the large cities near the coast, which traffic exists already to some degree. The canal across Florida, if made deep enough for ocean craft, would be used also for through traffic on account of its shortening the distance between the Atlantic and Gulf coasts. In the sections parallel with the coast, owing to the comparative shallowness of the water, the craft would have to be small and the speed low, as compared with deep-water navigation on the ocean. The total length of the land-locked route between Florida and either the Long Island Sound or the Mississippi River is greater than that of the straight ocean courses. For economical reasons there is a tendency to increase the tonnage of vessels, and greater speed is becoming more urgent. The sections along the coast, will, I think, therefore, be used mainly for local traffic. While heartily advocating the making of complete surveys and estimates

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* Mr. Crowell here submitted, as a substitute for the preambles and resolutions proposed by Captain McCorkle, others designed to avoid the features criticised by himself, and praying Congress to direct the preparation jointly "by the Chief of Engineers of the Army and the Director of the Coast Survey," of "a comprehensive and accurate map, or maps, and profiles of the entire coast line and route between New York Bay and the St. John's River in Florida;" but as these preambles and resolutions have since been superseded by those embodied by the Committee in their Report and transmitted with that Report to the various commercial bodies addressed, they are here omitted, at Mr. Crowell's request.

Publication Committee.

of costs for each particular section, and ascertaining the probable traffic, I think, the expected commerce (local and through) in each one should determine the advisability of its construction.

The remedy of a resolution to Congress, presented by the Club, as proposed, would not, I think, aid the matter, and I therefore do not favor it.

At a business meeting of the Club, held October 17, 1891, Captain Spencer C. McCorkle presented the following resolution:

Resolved, That the President be requested to appoint a committee of three to propose measures for bringing the subject of Land-locked Navigation before the Boards of Trade and other commercial bodies of the principal Eastern and Southern seaboard cities, with the view of preparing a joint memorial for presentation to Congress, urging the importance of the subject, and praying that the necessary preliminary steps be taken in that direction.

Captain McCorkle urged the necessity of interesting the various Boards of Trade and other commercial bodies in the project of perfecting the interior lines of water communication along our Eastern and Southern coasts, and then bringing the matter to the attention of Congress. The resolution, seconded by Mr. Trautwine, was adopted. The Chair subsequently appointed Captain McCorkle and Messrs. Foster Crowell and Rudolph Hering as the committee.

The committee was afterward increased to five, by the addition of Professor L. M. Haupt and Lieutenant-Commander William Swift, U.S.N.

At the meeting of December 5th, the Committee on Land-locked Navigation submitted preambles and a resolution expressing the gratification of the Club in view of the general awakening of interest in this project, and recommended that copies of the same be transmitted to the Boards of Trade and other commercial bodies of the principal seaboard cities, together with a digest of the route proposed and a letter of transmittal urging the advisability of memorializing Congress in favor of the plan.

On motion of Mr. Jacques W. Redway, it was ordered that the recommendations of the committee be carried into effect.

II.

ELECTRICAL TRANSMISSION OF POWER.

By A. Saunders Morris, Active Member of the Club.

Read October 3, 1891.

The transmission of power electrically has, in the last few years, one might almost say months, assumed such large proportions and is applied to such varied uses, that in a short paper it becomes impossible to consider the whole subject.

You are all more or less familiar with the distribution of power from the central lighting stations—a business which has grown rapidly and in some cities reaches proportions comparing very favorably with the demand for lighting. This refers especially to small motors fed from the system supplying lights. The system of electric street railways is another example of electric transmission which has become so universally introduced that it barely excites comment. The writer, however, proposes to limit himself in this paper to the transmission of power in large units as distinguished from its distribution.

Let us, before confining ourselves to Electric Transmission, glance for a moment at the other systems of transmission and their efficiencies as estimated by Herr Beringer.

DISTANCE POWER IS TRANSMITTED IN MILES.	HERR BERINGER.			WRITER.
	HYDRAULIC.	PNEUMATIC.	WIRE ROPE.	ELECTRIC.
$\frac{1}{2}$	50	55	91	77
1	49	54	8	74
3	41	51	61	71
5	37	50	43	70
10	26	43	21	65
13	18	39	11	62

From the table it will be seen that for distances of about two and a half miles and over, Electrical Transmission is the most efficient of the four systems, wire rope being the only one which

leads it for shorter distances. These electrical efficiencies are based on 90 per cent. efficiency of generator and motor respectively and a varying efficiency of line. The proper efficiency of the line, or, in other words, the energy lost between the generator and the motor, will depend upon the cost of the power, and interest and depreciation on the capital outlay. If the production of power is expensive it will, of course, be better economy to put more material in the line and lose less energy in the transmission. If we assume that 100 horse-power is available at the generator pulley, and that the efficiency of the generator and motor is 90 per cent. each, the horse-power delivered by the motor shaft will be 64.8 if the line efficiency is 80 per cent., and 72.9 if the line efficiency is 90 per cent. In the former case we will lose 18 horse-power in heating the copper line wire, while in the latter case but half that amount. The amount of copper in the line will be doubled in the latter case, but the cost of construction will be about the same. If we assume the cost of the motor to be proportional to the horse-power, it will be increased about ten per cent. We must therefore balance the additional cost of the line and motor against the value of the 10 per cent. additional power obtained at the motor pulley.

A few figures on the cost of transmission plants erected abroad by the Oerlikon Works may be of interest.

DISTANCE IN MILES.	HORSE-POWER DELIVERED.	GENERATORS.	MOTORS.	LINE.	TOTAL.*	PER H. P. DELIVERED.
1.87	85	$3,135	$2,741	2,155	$9,220	$108.50
.56	71	2,155	1,960	294	5,100	71.60
1.56	150	3,720	3,525	1,615	10,020	67.20
6.25	11	647	540	2,350	4,700	42.60
2.20	51	1,761	1,567	1,469	5,595	109.40
5.00	41	1,174	980	1,682	5,000	121.10
3.75	220	5,190	4,700	3,135	14,500	66.20
.43	510	. .	. .	. .	33,250	65.30

* This includes regulating apparatus, poles, insulators, lightning arresters, erection and supervision.

The last plant on the list is at Schaffhausen, and consists of two generators of 300 horse-power each, one twin motor of 390 horse-power, and two small motors of 60 horse-power each. The line consists of four stranded conductors having an area of .437 square inches each, and is supported at four points, exclusive of the termini. The manufacturers have guaranteed a commercial efficiency at ordinary full load of 78 per cent., also that the machines must be capable of transmitting an excess of 20 per cent. over the normal power for one hour and a half without damage. The wear of one set of brushes to be not less than 2,000 hours, and the life of a commutator not less than 2,000 hours. The variation of speed of the motors between running idle and under full load not to exceed 3 per cent.

In all of the previously mentioned plants direct or continuous current has been employed, but the difficulty of commutating currents of high potential has prevented the installation of many plants where the distances were so great that low potentials and heavy currents were financially impossible. This has led engineers to turn to the alternating current, not only on account of the ease with which it can be transformed from large quantity and low potential to small quantity and high potential and inversely, but also on account of the absence of commutators on either motor or generator. In avoiding the difficulties of commutation, engineers have been confronted by another—namely, the absence of an efficient alternating motor which would start itself. Any alternating current dynamo will run as a motor if it is brought up to speed in the first place; and further, unless very much overloaded, will maintain the same speed as the generator as absolutely as if it were mechanically coupled.

Another system of alternating current transmission has been devised, which overcomes the starting difficulty by the use of two or more currents differing in phase. This requires two or more wires, which are, however, in many cases unobjectionable. This is the type of generator and motor built by the Oerlikon Engineering Works for the Lauffen-Frankfort Transmission plant.

A short description taken from *The Electrician* of this 300 horse-power "multiphaser" may be of interest. This machine

is of the fixed armature and revolving field type. The armature is wound with three circuits, and with a speed of 150 revolutions will give 50 volts and 1,400 amperes in each circuit. The total weight without the bed-plate is 19,800 pounds, and its efficiency is said to be 96 per cent.

This transmission plant, which is the longest in the world, consists of the generator described above, located at Lauffen on the River Neckar, which furnishes currents of low potential to a bank of converters which, in turn, transform it to currents of small quantity at a pressure of about 25,000 volts. This is carried on the line to the Frankfort Exhibition, where it passes through a similar bank of converters, transforming the currents again to large quantity and low potential for the motor, which is a similar machine to the generator at Lauffen, but, of course, smaller. It may be urged that these several transformations of energy would result in an inefficient system; but if the reports are correct this is not so, for we estimate the efficiencies as follows:

Generator and motor, 96 per cent. each. Converters the same, and line 80 per cent., or nearly 68 per cent. for the commercial efficiency—a remarkably high figure when the distance, 112 miles, is considered. The reason for using converters instead of building a generator and motor for high potential, is that it would be practically impossible to insulate moving parts for this high potential, disregarding entirely the danger to attendants. The method of insulating these converters, to stand the enormous pressures to which they are subjected, is to place them in a tight case which is filled with oil. Thus any fissures or breaks which might exist in solid insulators are immediately filled by the oil. This method of insulation was used several years ago by Mr. David Brooks, of this city, in his underground conduit.

In this country the number of transmission plants is comparatively small, and reliable information as to cost and efficiency is very difficult to obtain.

The Brush Electric Company have installed at the Dalmatia mine in California a compound-wound generator, giving 40 amperes and 1,800 volts, which is driven by a Pelton water-wheel under a head of about 100 feet. The current is carried to the motor at the mine, a mile and a half distant, the power being used for driving stamps and other mining machinery.

In 1889 this company installed quite a novel plant at Virginia City, Nevada. The water-power available at the level of the stamp mill was entirely inadequate to drive all the machinery, consisting of some sixty stamps with their complement of agitators, etc. It was then proposed, after using the water on the upper level, that it should be carried down a distance of 1,680 feet to a chamber excavated in the Chollar mine and utilized for driving electric generators, the current being carried back to motors located in the mill. The generators are six in number, each generator being driven by a Pelton water-wheel. They are compound wound to give a constant current of 40 amperes. The wheels are 40 inches in diameter and are rated at 130 horse-power. The commercial efficiency of this plant is said to be 70 per cent., and the horse-power delivered is about 500. The installation is remarkable on account of the many difficulties which were encountered, such, for instance, as the moist atmosphere of the generator-room, being 78 per cent. saturation.

Another plant which is being installed by the same company is at the Calumet and Hecla mines. This plant consists of compound-wound generators, five in number, each capable of furnishing a current of 80 amperes at 970 volts, which is carried partly by an overhead line and partly by armored cable dropped through a bore-hole, a distance of about 8,000 feet, to the motors, also five in number, which drive the pumps. The speed of the generator is 850 and of the motors 920 revolutions per minute. The horse-power delivered by each motor is something over 80, and the efficiencies of the generators, motors and line being each about 90 per cent., we have a commercial efficiency of almost 73 per cent. This plant is to be run in competition with a pneumatic system.

Probably the only long-distance transmission plant in this country in which alternating current is used, was installed almost a year ago by the Westinghouse Electric and Manufacturing Company at Telluride, Colorado. The generator is capable of delivering about 30 amperes and 3,000 volts. The line is No. 3 B. & S. insulated wire, carried up the mountain on poles to the mine, a distance of 2.75 miles. This is a synchronous system—that is, as explained before, the motor and generator, being similar ma-

chines, run at exactly the same speed, irrespective of the amount of work done. The motor must, therefore, be brought up to speed by some auxiliary device, before the current is thrown on. In this case the starting device is a small two-phase motor. Its efficiency is not important, as it only has to run for about three minutes, when the current is switched from it to the synchronous motor, and the load thrown on. There are some very simple devices for automatically breaking the circuit, if the motor should drop out of step from excessive load; and as there is no commutator to look after, or regulation to be done, the plant requires very little attention. The cost of this plant, exclusive of erection and pole line, is said to have been $10,000, or about $100 per horse-power delivered, and its commercial efficiency about 75 per cent.

In conclusion, the writer has made no attempt to consider the best electro-motive force to be used, which must, to a certain extent, be decided for each case, being governed by surrounding conditions, such as cost of power, distance of transmission, and the like.

III.

ELECTRICAL TRANSMISSION FROM LAUFFEN TO FRANKFORT.

By Coleman Sellers, Active Member of the Club.

Read October 3, 1891.

The following information relating to the transmission of power from Lauffen to Frankfort, a distance of 175 kilometers, is recently obtained from letters from Switzerland.

The writer states that on the 14th of September he arrived at Lauffen at 11.30 A.M., where he was present at the starting of the 300 horse-power turbine supplying the power to a three-phase dynamo furnished by the Oerlikon Company. The tension of the current furnished by this machine is 65 volts only. These currents are sent into a transformer placed near the machine. The transformer carries the tension from 65 volts to 25,000 volts. The three-wired line from Lauffen to Frankfort has a diameter of four millimeters per wire.

The wires are supported by porcelain insulators with oil grooves, fixed on ordinary wooden telegraph posts. The distance between these posts is about 50 meters, or 164 feet. On arrival at the Frankfort Exhibition, the high-tension current is transformed again into an alternating current at 65 volts, which current supplied, on the evening of the 14th of September, on the one hand, 1,000 incandescent 16-candle lamps, and, on the other hand, a three-phase receiving dynamo of 100 horse-power furnished by the Allgemeine Electricitäts-Gesellschaft of Berlin, which is working in conjunction with the Oerlikon Society for the Lauffen experiment. The insulation works well, but nothing as yet can be said about the exact efficiency.

Up to the present time the power developed at Frankfort has not exceeded 120 horse-power, not because the efficiency is so low, but because the company fears accidents. It is intimated that there were some little difficulties at first, that made it prudent to wait until the month of October, toward the end of the Exhibition, to make tests at full power. Up to now the tension has not exceeded 15,000 volts instead of 25,000, and the quantity of

electricity has not exceeded 1,500 amperes instead of 4,000 on the primary current. The 100 horse-power dynamo furnished at present only 40 horse-power to a centrifugal pump.

It is a noteworthy fact that the ordinary ampere-meters and volt-meters give false indications—a phenomenon as yet unexplained, but resulting probably from a difference of phase between the maximum of tension and the maximum of quantity. The result is the surprising phenomenon that the number of watts, or the product of the amperes multiplied by the volts, is greater at Frankfort than it is at Lauffen. This result, which would indicate an efficiency of more than 100 per cent., is, of course, only apparent. A special watt-meter must be constructed in order to measure exactly the currents at the start and at the arrival.

It is understood that a special commission, under the presidence of Prof. Weber, professor of the Polytechnikum of Zurich, will proceed to a complete series of experiments to ascertain exactly the efficiency of the installation running at full power. There is general satisfaction felt at the choice of Prof. Weber for this position.

The interesting part, to this country, is that what has been accomplished at Frankfort is very favorable to the lesser effort contemplated of sending power from Niagara to Buffalo, the distance being only about 32 kilometers, or 20 miles, as compared to 175 kilometers, or 109 miles.

I should have mentioned that there are enthusiastic advocates of the alternating current in Europe, who are not entirely committed as to the advantages of this three-phase dynamo as proposed by the Oerlikon Company, believing that as good results in efficiency will be obtained with the Mordey alternator, which has been demonstrated to me by actual experiment to be as efficient for a motor as a dynamo, with the great merit of simplicity and durability, the rotating motion being given to the field magnets, making the more delicate armature stationary and not liable to be disarranged.

The students of this subject of the transmission of power will do well to examine the paper recently read by Prof. Unwin on "The Transmission and Distribution of Power," the calculations

being based upon experiments on air-motors, by Prof. Reidler and Prof. Gutemuth, and it shows a very favorable outlook for the transmission of power to the distance of at least twenty miles as being practicable, as it seems that air compressed by 10,000 horse-power to $132\frac{3}{10}$ pounds per square inch, can be transmitted to a distance of twenty miles in a 30-inch main with a loss of pressure of only 12 per cent. The power delivered at a distance of 20 miles by using compressed air can be counted upon as yielding 40 to 50 per cent., if the air is used cold, and 59 to 73 per cent. if the air is re-heated.

In regard to the re-heating of air, experiments have been tried in this country by Mr. Saunders of New York, of applying the combustion within the air mains, with the result that leaves little to be desired, inasmuch as the whole product of combustion is added to the quantity of compressed air, and the heated combustion is used in increasing the efficiency of the transmission.

IV.

THE EFFECT OF CENTRIFUGAL FORCE ON THE TRANSMITTING POWER OF DRIVING ROPES.

By Barton H. Coffey, Active Member of the Club.

Read October 3, 1891.

The increasing employment of the rope-drive for transmitting large powers, renders any factors affecting its capacity of importance.

I wish to present a purely theoretical treatment of the effect of centrifugal force in diminishing this capacity at high speeds. The sides of the rope-grooves are straight, and form an angle of 45°, tangent to the circle of the rope. A greater driving power is thus obtained through the wedging action of the ropes in these V grooves.

The power transmitted will depend chiefly on the tension of the rope, the arc of contact and the speed; the safe tension, of course, implying the section of the rope.

English tests give the following results at 2,000 feet per minute:

1″	rope	— 7	horse-power.
$1\frac{1}{4}$″	"	— 13	"
$1\frac{1}{2}$″	"	— 20	"
$1\frac{3}{4}$″	"	— 28	"
2″	"	— 36	"

These horse-powers do not vary in the simple ratio of the square of the diameter, and after considerable calculation the following empirical expression was found to follow these results very closely:

$$(D^2 + D - 1) \ldots\ldots \text{(I.)}$$

D = diameter of rope in inches, and neglecting centrifugal force, the following formula gives the power:

$$H.P. = V\left(\frac{D^2 + D - 1}{280}\right) \ldots\ldots \text{(II.)}$$

where V = velocity in feet per minute.

This is safe for speeds somewhat in excess of 2,000′ and all

under it. At high speeds, however, the effect of centrifugal force in lessening the driving tension becomes so marked that it is necessary to take it into consideration. The following formula was deduced to make this correction:

$$H.P. = V\left(\frac{2{,}700\ A - WV^2}{11{,}180}\right)$$

V = velocity in feet per second,
$A = (D^2 + D - 1)$,
W = Weight of a foot of rope in pounds.

This expression was deduced as follows:

$$\text{From (II.)}\quad H.P. = \frac{PV}{33{,}000} = V\left(\frac{D^2 + D - 1}{280}\right).$$

$\therefore$ P the driving force varies as (A) and equals $C(A)$.

With a friction coefficient of .70 we find that the mean tension $\left(\frac{T_1 + T_2}{2}\right)$, when the rope embraces .5 of the wheel, equals .63 P. The expression for centrifugal force is $\frac{WV^2}{gR}$, W = weight, V = velocity, and R = the radius.

The centrifugal tension, therefore, equals:

$$\frac{WV^2}{g} \quad \ldots\ldots \text{(III.)}$$

The mean tension at any speed, including centrifugal force, will therefore be

$$\frac{.63\ P - \frac{WV^2}{g}}{.63\ P} \quad \ldots\ldots \text{(IV.)}$$

The power will vary with this mean tension, therefore, at any speed:

$$H.P. = \frac{PV}{550} \times \frac{.63\ P - \frac{WV^2}{g}}{.63\ P} \quad \ldots\ldots \text{(V.)}$$

Cancelling P and substituting constants:

$$H.P. = V\left(\frac{20.3\ P - WV^2}{11{,}165}\right) \quad \ldots\ldots \text{(VI.)}$$

Substituting $P = C(D^2 + D - 1) = C(A)$:

$$H.P. = V\left(\frac{20.3\ C(A) - WV^2}{11{,}165}\right) \quad \ldots\ldots \text{(VII.)}$$

To obtain the value of C, we substitute a known value of H.P. from the experiments, in VII. Taking the 2″ rope at 2,000′,

$V = 33\frac{1}{3}'$ per second,
$A = 5$,
$W = 1.08$ pounds,
$H.P. = 36$.

On reducing these values in VII, and solving for C, we find it equals 131. And substituting in VII, we have:

$$H.P. = V\left(\frac{2660\ A - WV^2}{11{,}160}\right) \ldots\ldots \text{(VIII.)}$$

It was found, in calculating the following table, that the results were improved by slightly increasing the constants. At 2,000 feet per minute the centrifugal force absorbs about 10 per cent. of the transmitting power of the rope; it rapidly increases until, at about 7,000, there is practically no power left.

The point of maximum power appears to be at about 3,800′ per minute; after that point is reached, any increase of speed decreases the H.P. transmitted.

TABLE OF HORSE-POWERS

Transmitted by cotton ropes at various speeds, and for different diameters of rope, the ropes being considered as embracing fifty per cent. of the circumference of each pulley. (For other arcs of contact, see coefficients below.)

Velocity, feet per minute.	Diameters of Ropes.						Velocity, feet per minute.	Diameter of Ropes.					
	2¼″	2″	1⅞″	1¾″	1½″	1¼″		2¼″	2″	1⅞″	1¾″	1½″	1¼″
1,500	36.3	28.8	25.3	21.9	15.7	10.3	4,200	65.1	51.1	45.5	38.6	27.3	16.6
1,800	42.5	33.6	29.7	25.7	18.4	12.0	4,500	63.8	50.3	45.0	38.3	26.2	15.6
2,100	48.3	38.2	33.6	29.1	20.8	13.6	4,800	60.0	47.2	42.4	36.4	24.5	14.1
2,400	53.2	42.0	37.2	32.2	22.9	14.9	5,100	55.3	42.9	40.0	33.6	22.1	12.1
2,700	57.6	45.5	40.5	34.8	24.7	15.9	5,400	49.5	38.3	36.0	29.9	19.0	9.5
3,000	61.0	48.5	42.8	36.9	26.2	16.8	5,700	40.9	31.8	30.4	25.1	15.2	6.5
3,300	63.8	50.6	44.5	38.5	27.2	17.3	6,000	32.0	24.0	24.0	19.3	10.5	2.8
3,600	66.0	51.6	45.9	39.5	27.8	17.4	6,300	20.0	15.0	15.8	12.5	5.0	0.0
3,900	65.7	52.0	46.2	39.9	27.8	17.2	6,600	6.7	0.0	7.7	4.5	0.0	0.0

Correction Factors.

To compensate for the effect of a variable arc of contact between pulley and rope, multiply above results by the proper factor of correction.

Arc of Contact, per cent. of circumference.	.20	.30	.40	.50	.60
Factor of Correction.	.52	.72	.90	1.00	1.09

V.

SOFT STEEL IN BRIDGES.

By F. H. Lewis, Active Member of the Club.

Read October 17, 1891.

It is not to be expected that a bridge specification, prepared at this time, will contain much that is new or novel. It will, no doubt, contain something of the individual tastes and preferences of the party who expects to use it; if, with this, it is fortunate enough to include the approved features of existing specifications, a new idea or two will quite suffice for novelty. The specification accompanying this paper is, in fact, a revision of an older specification, which, in turn, derived its salient points from the well-known specification of the Keystone Bridge Company. Features of this specification, and also of other well-known specifications, will be apparent to the initiated. It is not my purpose, therefore, to enlarge upon the subject-matter in any general or extended way, but to confine my remarks chiefly to one feature.

It will be evident to anyone who examines the unit strains, that they are expressly intended to put soft steel on at least an equal footing with wrought iron and medium steel; and the idea in laying the specifications before the Club at this time, was to have this feature fully discussed for the mutual benefit. While, therefore, any part of the text is open for criticism or suggestion, the steel question is the primary one, and to that alone I propose to address myself.

There are, at this time, three grades of material offered to engineers for structural work—viz., wrought iron, soft steel, and medium steel. Of these we are using wrought iron for short spans, and medium steel for long spans, while the soft steel, which is in many respects the best grade of material of the three, we are using very little, and there seems to be no immediate prospect, under existing specifications, of extending its use.

It has been my good fortune to have an intimate acquaint-

ance, at first hand, with the character of the material now being turned out by our manufacturers, and to have been much impressed, in consequence, with the idea that in neglecting to use soft steel we are doing so to the disadvantage of our bridge structures, and that it is really important to give it a standing in specifications, which will allow it to be used on at least equal terms with the other grades of material.

Our wrought iron is certainly not improving in quality, and in certain directions it is distinctively poorer than it formerly was. In the manufacture of steel, however, there has been a notable improvement in quality and uniformity, and the best qualities of soft steel now leave very little further to be desired. As compared with wrought iron, we have a material which, with 15 per cent. higher ultimate strength, has from 20 to 25 per cent. higher elastic limit, and from 50 to 60 per cent. greater ductilility. We have a material which has equal strength, ductility and bending qualities, lengthwise and crosswise of the material, in comparison with wrought iron, which has little strength or ductility and will not bend across its grain. We have, again, a material which has no fiber, and which, consequently, has less disposition to tear or pull out; and, lastly, we have the fine finish and sound, clean metal characteristic of steel, in comparison with the rougher finish and frequently doubtful welding of wrought iron.

Now, in certain well-known specifications, and with the tacit consent of many engineers, our bridge builders have been privileged, for several years past, to use soft steel on the same basis as wrought iron; at no time, however, have they taken advantage of this privilege to any great extent, and it seems quite uncertain whether they will do so. We get a little soft steel occasionally when there are long bars to be rolled, which can be gotten out easier in steel, or when there is a nice order of plates that can be rolled more economically, and we get occasionally pieces of steel in our structures for other purposes; but anything like a general use of it has not come to pass, and the very simple reason is that it costs more. I have endeavored to ascertain from our manufacturers whether the relative difference between wrought iron and soft steel would be likely to decrease soon, but, so far as I

have been able to ascertain, none of them are prepared to commit themselves on this subject. It seems likely, if there is a considerable market for it, under a standard specification, that the cost will be reduced to that of wrought iron, or lower; but it also seems likely that this will not transpire until we do use it and cheapen it by making a market for it.

Within the last few years quite a number of engineers have evidently formed favorable opinions of this grade of material and have essayed to use it, but under conditions which do not seem to be entirely warranted. In one or two cases they are reaming it, just as they would medium steel; but this can hardly be regarded as an advantageous procedure, because, first, the metal is not of a character adapted to reaming, being of a soft, waxy texture, which drags on a tool and clogs it, making more expensive work than medium steel; and, second, we are not warranted in figuring it at high enough unit strains to cover this expense. We might, perhaps, rate the unit strains at 15 per cent. higher than wrought iron, but such a percentage will certainly not pay the cost of reaming, added to the extra cost of the material. Again, several engineers have been using soft steel under the same conditions as wrought iron, but with the higher strains which have been adopted for medium steel. It is an open question whether such a course as this is warranted by the facts of the case. It is not necessary, in the first place, to figure it so high, to place it on a par in cost with wrought iron; and then the material is certainly not of equal value with reamed medium steel, for the reasons, first, that its elastic limit and ultimate strength are both lower; and, second, because reaming undoubtedly adds to the value of any grade of steel, or of wrought iron, for that matter.

The correct solution of the matter would appear to be to strike a balance between the cost of soft steel in bridge structures, as compared with wrought iron on the one hand, and medium steel on the other, and to rate it accordingly, if we are fully warranted to do so, at unit strains high enough to overcome the difference in cost. The present difference in cost between wrought iron and soft steel may be reckoned about as follows:

Cost of wrought iron, say	100
Increased weight of steel 2 per cent.	2
	102
Add increased cost of soft steel 5 per cent. (not well maintained)	5.1
Total	107.1

In other words, the cost of soft steel is nominally a little over 7 per cent. higher than wrought iron. In the shop there would be a slight saving in using soft steel due to a rivet saved here and there, and other small savings, provided we can use it just like wrought iron.

I take it for granted that the propriety of using soft steel, having an average ultimate strength of 58,000 pounds at unit strains in compression 10 to 15 per cent. higher than wrought iron, will not be seriously questioned. I mean by this under the actual conditions in which it is used in our bridges—that is, with values of $\frac{l}{r}$ not exceeding 150. The propriety of using soft steel under higher unit strains than wrought iron, hinges then upon its qualities in tension in flanges of girders and in the tension of members of trusses; and this phase of the subject I propose now to discuss somewhat at length: Whether soft steel, after punching, constitutes a good tension member.

If left to our practical shopmen, there would probably be no hesitation whatever on this score. It is, perhaps, no exaggeration to say that for exacting conditions of all sorts it is becoming more and more the practice to substitute soft steel. It is being used for latticing, because it will not split; it is being used for the hitch angles of stringers and floor beams, because it will not crack; it is being used for pin plates on suspenders, and in various other ways where its superior qualities have been practically shown to practical men.

It is necessary to get more conclusive evidence than this, however, and the presentation of this evidence, as I have been able to collect it, follows below.

Lest the discussion should take a wrong tack, however, let

me say at the outset that in nothing which follows is there any attempt to show that reaming is not a good thing *per se*. On the contrary, the tests given below show that it generally benefits soft steel whenever the metal is over $\frac{3}{8}''$ thick. It is better to state this very clearly, because otherwise the discussion might hinge on the relative merits of punching and reaming, which is not now at issue. We cannot ream soft steel and use it economically.

The question is not, therefore, whether punching is better than reaming, but whether we are as fully warranted to punch soft steel as we are to punch wrought iron. We are punching iron for all conditions of work; and if soft steel holds its value after punching as well as or better than iron, then we are clearly free to use it in the same way.

To test the question it is only necessary to take tested samples of iron and steel, and after punching them under the same conditions, again test them, and by simple rule of three ascertain which holds its value best. This has been done in tables which follow. Except where noted in the tables, the values obtained in specimen tests are always rated at 100, and the values after punching are rated by percentage from this basis. Having thus cleared the way, let me call your attention to Table I:

TABLE I.

U. S. Government Tests of Riveted Joints at Watertown Arsenal.

Reports of 1882–3.

Punched Holes.

Specimen.	Kind of joint.	Iron. Ultimate. Specimen test.	Iron. Ultimate. Net section joint.	Iron. Perct.	Steel. Ultimate. Specimen test.	Steel. Ultimate. Net section joint.	Steel. Perct.
10″ x ¼″ plate	single lap	47,925	43,230	90	55,765	60,250*	108
		"	45,520	95	"	59,240	106
		"	52,160	109			
		"	54,930	115			
" "	double lap	"	50,592	106	"	61,510	110
		"	49,950	104	"	60,300	108
				103			108
10″ x ⅜″ plate	single lap	47,180	36,130	77	53,330	55,215*	104
		"	41,750	89	"	65,460	123
		"	41,290	87	"	65,210	122
		"	61,700	131	"	73,394	138
		"	58,510	124	"	73,970	139
" "	double lap	"	48,450	103	"	62,800	118
		"	50,730	108	"	64,720	121
		"	46,255	98	"	63,210	119
		"	46,110	98	"	54,930	103
				102			121
10″ x ½″ plate	single lap	44,615	31,100	70	57,215	60,210	105
		"	31,395	70	"	49,590	87
		"	35,650	80	"	47,530*	83
" "	double lap	"	44,320	99	"	64,602	113
		"	42,920	96	"	64,519	113
		"	46,400	104	"	68,920	120
		"	46,140	104	"	66,710	118
				89			105
10″ x ⅝″ plate	single lap	44,63	34,680	78	52,445	52,770*	101
		"	34,230	77	"	49,610*	95
" "	double lap	"	43,580	98	"	69,680	133
		"	45,850	103	"	67,100	128
				89			114
10″ x ¾″ plate	single lap	46,590	29,290	63	51,545	39,970	78
		"	30,730	66	"	47,370	92
	double lap	"	42,000	90	"	48,970	95
		"	43,950	94	"	47,510	92
				78			89

* Did not rupture the plate.

This table is derived from a series of tests of riveted joints, which appear in the Government Reports of tests made at the Watertown Arsenal. In this series of tests, with which many members are, no doubt, familiar, steel and wrought iron were compared under practically the same conditions through a long series of tests of both punched and reamed material, and the ultimate strengths of the samples were very carefully determined by specimen tests. The conditions were not always exactly identical, as the rivets were sometimes of wrought iron and sometimes of steel, and the joints failed accordingly, sometimes by shearing the rivets and sometimes by tearing the plate.

I have endeavored, however, in this table to compare, on essentially similar terms in each case, the behavior of the wrought iron and of the steel. The table includes, I think, every punched test in the series which failed by tearing across the sheet, and also includes a few tests which failed by shearing, but which evidently developed nearly the full value of the material. These last tests are indicated by stars.

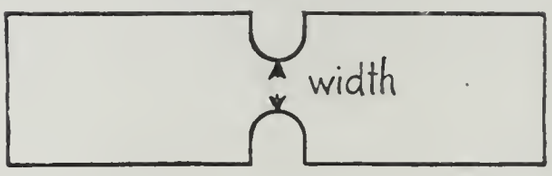
Unfortunately the elastic limit was not determined in these tests, and no comparison can, therefore, be made between the elastic limit of the specimens and the elastic limit of the riveted joints. The ultimates, therefore, only are compared, and the relative ultimate strength developed in net sections at the joints is figured out in the columns headed "Percentage" throughout the table. You will find that not only does the steel show less loss in ultimate strength as an effect of punching than the wrought iron as an average of these tests, but in every identical test, with one exception, this fact is also true, and as the thickness of the pieces ranges from $\frac{1}{4}''$ up to $\frac{3}{4}''$, the series is very complete. It is true, some of this steel is a little softer than the soft steel which it is proposed to use for bridge structures; but, on the other hand, the iron is also of good, soft quality, probably boiler-plate iron, as the tests indicate it to have an unusually large percentage of strength across the grain. It would, therefore, probably give better results than ordinary wrought iron would, and the comparison is, therefore, a fair one.

Table II is also from the Government tests at Watertown, and consists of comparative results obtained from grooved specimens alternately drilled and punched. The percentages of this table are made up by rating the ultimates of the drilled specimens at 100, and in this table also it will be found that the steel is less impaired by punching than the wrought iron. The steel and iron used in these tests is the same batch of stuff as that tested in Table I.

TABLE II.

U. S. Government Tests of Grooved Specimens at Watertown Arsenal

Reports of 1882.



Iron.			Specimen.	Steel.		
Drilled.	Punched.	Perct.		Drilled.	Punched.	Perct.
44,980	38,950	86	$\frac{1}{2}''$ x 3″ wide	66,310	60,320	93
47,030	37,200	79	" "	66,190	62,430	94
45,330	35,730			64,470	48,010	
45,000	36,690	81	$\frac{1}{2}''$ x 4″ "	64,810	55,190	80
46,100	37,000			64,690	55,780	
	37,420			64,140	46,250	
		82				89
47,220	49,770	105	$\frac{5}{8}''$ x 1″ wide	60.290	66,720	110
48,350	52,960	110	" "	63,610	64,800	102
47,170	46,320	98	" "	63,450	64,400	102
46,350	46,750	101	" "			
48,220	40,140	83	$\frac{5}{8}''$ x 3″ "	59,270	57,180	96
44,840	37,310	83	$\frac{5}{8}''$ x 4″ "	60,330	54,450	90
45,100			" "	61,120	57,380	94
		97				99
47,500	50,840	107	$\frac{3}{4}''$ x 1′ wide	58.480	67,930	116
52.780	46,590	88	" "	58.790	67,630	115
48,470	45.970	95	$\frac{3}{4}''$ x $1\frac{1}{2}''$ "	59,290	62,890	106
47,750	40,350	84	$\frac{3}{4}''$ x $3\frac{1}{2}''$ "	58,700	56,730	96
46,350	39,380	85		59,180	54,220	92
		92				105

Note.—In this table the punched pieces are not compared with specimen tests, but with drilled pieces prepared like the old Government boiler test As the punched iron does not rate as high as the punched steel in this table, drilling is clearly of more benefit to the iron than to the steel.

In these Government Reports will also be found some interesting tests on ths tearing out of rivet holes in steel and iron. Unfortunately the series is limited to $\frac{1}{4}''$ metal, and is consequently of limited value. In $\frac{1}{4}''$ stuff the difference between punched and drilled holes is very small indeed. So far as these tests go, however, they show that steel with punched holes and sheared edges gives better relative results than iron with drilled holes and planed edges.

Not long since, it was my good fortune to find a very interesting series of comparative tests of iron and steel on record at one of the larger iron works of this district, and through the courtesy of the proprietors I have been able to examine it to determine the same ratios given in the tables above. As the complete results will probably be published, I cannot give the details, but only the general results. The tests are important, because punched, reamed and drilled specimens of iron and steel are compared

under exactly similar conditions, and the series comprises some fifty or sixty tests. The bars used for the purpose were 6 x $\frac{1}{2}$, 6 x $\frac{5}{8}$, and 6 x $\frac{3}{4}$ respectively in both iron and steel, the steel having an ultimate strength of about 64,000 pounds, and the iron an ultimate strength of about 52,000 pounds, and both grades of material were of excellent quality.

I have checked up the entire series and find that the steel is very uniformly less injured by punching than iron, the average difference being about 10 per cent. in favor of steel, and this difference is essentially true of all tests save, perhaps, one in the series. Thus, if we rate the average ultimate strength of the steel in specimen tests at 100, the average ultimate of the iron in specimens tests would rate at 83; but rating the average ultimate of the punched steel on net sections at 100 per cent., the average ultimate of punched iron on net sections would rate at 71$\frac{1}{2}$ per cent. More than this, a comparison of the punched specimens with the reamed ones in both cases shows the iron to have been quite as much benefited by reaming as the steel.

Below (Table III) are given some tests of wrought iron, soft steel and medium steel, which have been made recently under the auspices of the Pittsburgh Testing Laboratory. Some of the specimens were tested with open holes and some with rivets in the holes.



Fig. 1.

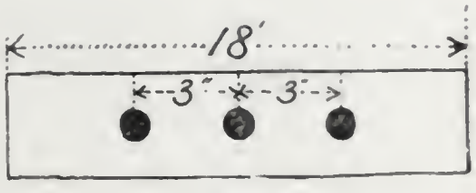


Fig. 2.

TABLE III.

Tensile Tests of Specimens of Soft Steel and Wrought Iron Having Punched Holes. Also, Comparative Tests with Reamed Holes.

	Test cut from.	Specimen test.			Punched piece.				Reamed piece.			
		E. L.	Ult.	Elong.	E. L.	Pr. Ct.	Ult.	Pr. Ct.	E. L.	Pr. Ct.	Ult.	Pr. Ct.
Soft Steel Riveted Holes.	7″ x ¼″ flat.	Assumed.	60,000		58,840		64,239	107	60,899		64,900	108
	8″ x $\frac{5}{16}$″ flat.	34,250	54,480	22.50	50,780	148	59,600	109	53,109	156	62,100	114
	15″ x ⅜″ plate.	39,410	55,540	31.00	51,620	131	61,220	110	52,220	133	66,900	120
								108.7				114
					Av. elong. in 8″ = 8.00 per cent.				Av. elong. in 8″ = 7.92 per cent.			
Soft Steel Open Holes.	*6″ x ¼″ flat.	38,200	58,300	26.50	46,200	121	62,200	107				
		39,800	62,490	25.30	45,300	114	65,900	106				
		39,790	63,500	25.00	45,500	115	68,300	108				
	*6″ x ⅜″ flat.	39,500	62,600	27.60	43,800	111	62,100	99				
		40,100	64,200	28.20	48,200	120	59,900	93				
		40,100	64,000	27.50	41,800	104	63,100	99				
	4″ x 3″ x ⅜″ angle.	39,180	58,910	26.25	38,170	98	50,310	85	40,250	103	61,320	103
	12″ x ½″ flat.	41,370	55,900	32.25	47,450	114	48,960	88	42,870	103	64,820	116
	19½″ x $\frac{9}{16}$″ plate.	35,820	56,460	32.25	38,950	109	52,409	93	41,570	116	61,450	109
	12″ x $\frac{9}{16}$″ flat.	35,650	62,210	30.00	35,310	99	58,890	95			63,270	102
	18″ x $\frac{15}{16}$″ plate.	37,540	55,540	31.50			45,080	81	39,440	108	63,450	114
	14½″ x ⅝″ plate.	34,710	57,520	30.75			43,820	76	38,260	120	64,660	112
	8″ x $\frac{11}{16}$″ flat.	40,690	60,540	31.00	44,170	109	45,500	75	44,140	109	63,030	104
	18″ x ¾″ plate.	35,240	55,350	33.75	40,070	114	41,180	74				
								91.4				108.6
					Av. elong. in 8″ = 4.19 per cent.				Av. elong. in 8″ = 10.20 per cent.			
Wrought Iron Open Holes.	7″ x ⅝″ U. M. plate.	30,140	45,000	7.75	31,740	105	36,609	81	33,510	111	46,870	104
	6⅛″ x ⅜″ U. M. plate.	34,790	51,390	15.00	36,150	104	40,570	79	33,320	95	44,240	86
	6″ x 4″ x ⅜″ angle.	34,080	50,560	18.00	34,300	101	36,459	72	34,360	101	42,360	84
	6″ x 6″ x $\frac{7}{16}$″ angle.	33,059	49,870	17.25	35,720	108	36,670	74	34,520	105	43,580	87
	6″ x 6″ x ½″ angle.	33,680	48,830	25.00	36,160	97	40,240	82	35,180	104	46,660	96
	6″ x 6″ x ½″ angle.	32,690	47,990	16.00	33,620	103	36,510	76	34,040	104	44,970	94
	12″ x ½″ plate.	32,750	49,800	24.00	36,250	111	38,460	77	34,540	105	47,490	95
	14″ x ⅝″ plate.	30,170	49,780	24.25	34,800	115	37,140	75	35,280	117	52,060	105
	16″ x ¾″ plate.	29,690	48,800	24.75	34,800	117	37,550	77	33,080	111	43,689	89
	14″ x ¾″ plate.	30,430	49,160	28.00	34,260	112	37,500	76	32,970	105	42,630	87
								76.9				92.7
									Av. elong. in 8″ = 5.83 per cent.			

* These six tests were 6 inches wide and had 3 holes across the section as in Fig. 1, the pitch varying in the different tests. All the other tests above were of the form shown in Fig. 2, and nearly all of them were 3 inches wide with $\frac{15}{16}$ inch holes. In punched pieces holes were punched $\frac{15}{16}$ inch; in reamed pieces punched $\frac{13}{16}$ inch, and reamed to $\frac{15}{16}$ inch.

In these tests the elastic limit was taken in all cases, and it will be observed that with punched holes the material retains its full value at the elastic limit, and indeed generally records a gain in this respect, showing the punching to have made the metal harder and denser.

In the series of tests with rivets driven in the holes, it is evident that generally the rivet acted as a splice, and the elastic limit is really that of the gross section. The tests on their face hardly indicate as high values as this, but the fact seemed to be as stated. The heating in riveting no doubt softened the metal and reduced the elastic limit.

A number of tests of punched medium steel are given, and also two of hard steel. With the exception of the latter grade of metal, a comparison of results decidedly favors the steel.

TABLE IV.

TESTS OF MEDIUM STEEL AND HARD STEEL.

	Test cut from		Specimen test.			Punched piece.				Reamed piece.			
			E. L.	Ult.	Elong.	E. L.	P.ct.	Ult.	P. ct.	E. L.	P.ct.	Ult.	P. ct.
Medium Steel Riveted Holes.	8″ x $\frac{5}{16}$″	plate		69,280	20.25	51,080		70,460	102	57,010		72,700	105
	14″ x $\frac{1}{2}$″	"	41,750	67,600	20.50	45,550	109	66,190	98	53,460	128	72,180	107
	10$\frac{1}{4}$″ x $\frac{21}{32}$″	"	39,460	68,540	29.38	48,900	124	56,690	83	41,720	106	71,630	105
	6″ x 6″ x $\frac{3}{4}$″	angle	40,090	66,340	25.38	45,970	115	53,300	80	46,990	118	68,550	103
	"	"	38,400	67,070	23.00	45,100	118	52,300	78	47,450	124	66,840	99
									88.2				103.8
						Av. elong. in 8″ = 4.70 p. ct.				Av. elong. in 8″ = 8.75 p. ct.			
Medium Steel Open Holes.	7″ x $\frac{3}{8}$″	plate	41,190	61,080	19.50	40,610	99	54,260	89	45,420	110	58,980	97
	6″ x 6″ x $\frac{1}{2}$″	angle	33,010	66,790	23.75	33,950	103	63,540	95	35,710	108	66,740	104
									92				100.5
						Av. elong. in 8″ = 8.50 p. ct.				Av. elong. in 8″ = 12 p. ct.			
Hard Steel Open Holes.	15″ x $\frac{3}{4}$″	plate	48,380	81,120	22.25	55,430	115	57,420	71	67,500	139		
	*7″ x $\frac{7}{16}$″	"	44,890	73,040	22.75	46,000	102	55,200	69	43,770	98	71,210	98
									70				

* This specimen had a flaw in it. Form of specimens same as in Table III.

Now it will be evident to any one who examines the facts presented, that there are several points suggested by these tests which are not proved and which can only be demonstrated by more extended tests. The field for such experiments is evidently an ample one. But on the definite question raised in this paper I submit that the tests presented, whether considered as a whole or in detail, are positive evidence that the tensile strength of structural steel is injured rather less by punching than is the tensile strength of wrought iron. It is not my intention to claim that this demonstration is conclusive, much less exclusive of testi-

mony to the contrary. But it is entirely true so far as the evidence goes, and this evidence, as presented, is entirely full and candid, including everything which I was able to find bearing on this subject, and the entire series of 90 special tests made under my own direction. I have no idea that it can be successfully gainsayed.

As conclusions suggested, but not demonstrated, let me note the following:

(1) The thicker the metal the greater the injury in punching steel.

(2) The softer the steel the less the injury in punching; but,

(3) The first conclusion is the major factor; the grade of the steel making much less difference than the thickness of the material.

(4) The effect of riveting is advantageous, increasing the values of net sections.

Conclusions 1 and 2 have ample support from other sources and may be considered as facts. Thus, Kirkaldy's recent book, in commenting on his well-known series of tests of Fagersta plates, speaks as follows: "Punching is less detrimental the softer the plate; the great difference produced by punching is due to its *hardening* effect upon the plates, which becomes more severely felt as the thickness increases." In proof of this he then gives the elongation of holes at the fracture, in a series of tests of $\frac{1}{8}''$, $\frac{1}{4}''$, $\frac{3}{8}''$, $\frac{1}{2}''$ and $\frac{5}{8}''$ plates, as follows: With drilled holes 5.7, 14.1, 17.2, 18.7 and 19.0 per cent., with fractures all silky; with punched holes 3.2, 9.6, 13.5, 3.2 and 1.9 per cent., with the last two fractures showing 95 and 100 per cent. granular respectively.

Then he anneals the specimens in a similar series, to remove the hardening effect, and gets elongations as follows: With drilled holes "extensions of 11.5, 16.3, 19.4, 21.0 and 21.9;" with punched holes "10.3, 14.6, 18.1, 19.3 and 20.7 per cent., all fractures being wholly silky." This makes a very pretty demonstration.

Kirkaldy compares the ultimate strength of drilled and punched specimens in these same tests, as follows: When not annealed, the strength of punched pieces as compared with drilled ones showed losses of 7.92, 8.10, 7.53, 23.45 and 26.22 per

cent. respectively. When he anneals the specimens, however, the punched pieces show losses of but 5.85, 6.70, 6.74, 7.08 and 7.18 per cent. respectively.

"This manipulation or treatment rectifies the injuriousness of punching to a great extent," he says. This is argument for conclusion No. 4, because, evidently, so far as the rivets anneal and soften the metal they benefit it and lessen the injury in punching; and, evidently also, this advantage accrues more to thick metal than to thin, because the original injury was greater. I think the tables in this paper offer evidence that this beneficial effect of riveting is an actual fact; certainly, the riveted pieces show higher percentages than the pieces with open holes.

Regardless of any such effect, however, the fact that punching is more injurious in thick material makes it desirable to use moderate sections in tension members and in floor-beams, stringers, and girders subject to impact.

In concluding the discussion of the tables, your attention is called to the elongation of the punched steel pieces in a length of 8 inches. The stretch is, of course, necessarily confined chiefly to the three holes, but the percentages are given in 8-inch length to show what it might be expected to average in any long riveted member.

Having thus reasonably demonstrated above an equal standing for our punched steel, we could logically claim for it unit strains from 12 to 15 per cent. higher than for wrought iron.

In the specifications, however, it was thought well to be conservative on this point, especially as it is not necessary to figure soft steel so much above wrought iron in order to make the cost practically the same. The unit strains, therefore, for soft steel in tension are placed at 8 per cent. higher than wrought iron, and in compression 10 per cent. higher. These figures are conservative, and the balance left over is so much advantage to the bridge structure.

It will be observed that web plates are required to be of steel, in all cases. It is, of course, impracticable to reach web plates by difference in unit strains. It would, however, be absurd to use steel angles in connection with an iron web, since the equal strength of steel plates in all directions exactly fills the condition of a web sheet, and makes them particularly desirable for such purposes. There

is, besides, good reason for throwing iron web plates out altogether, because of poor quality. It is doubtless no longer profitable to make a first-class iron web plate, hence many of those now sold are of very doubtful quality, and owe whatever virtues they possess to the percentage of steel which they contain. It will be noted that both iron eye-bars and soft steel eye-bars are ruled out of the specifications. Excepting with the most conservative, the iron bar has already been practically superseded, because steel bars are now cheaper and have, besides, abundantly demonstrated their superiority. As regards soft steel bars, there is no reason, on the face of it, why soft steel should not make a good eye-bar; it doubtless would; but medium steel has been found to answer the requirements with entire satisfaction, and, after annealing, is considerably softer than when tested in its natural state in small specimens.

There is a practical reason also for not using soft steel in the fact that it is more apt to have piping and blow-holes in it than medium steel. This is not objectionable in angles or plates, where these defects close up and disappear; but it is objectionable in large masses, like pins and forged bars. It was not thought worth while, therefore, to introduce a soft steel eye-bar in the specifications. The result is, that the soft steel is limited to compression members, to girders and to riveted tension members, and the idea in fixing the unit strain has been to place it for these purposes on a par with other material; possibly to give it a little advantage to overcome the inertia of manufacturers who have been accustomed to using wrought iron only. It is possible that it is not necessary to make as much allowance as has been made, or perhaps it should be modified a little more to suit different cases.

This matter is laid before the Club for discussion, and it is hoped that some information in regard to cost of soft steel and the probabilities of reducing its cost will come to light.

There is one point more that may require special mention—that is, the provision of the specifications permitting steel bars to be used with upset screws on their ends. This is probably the last point which engineers are ordinarily willing to concede in regards to steel; that is, the possibility of putting a screw-thread on it; nevertheless this may be done with entire success, and in evidence thereof the following tests are submitted.

PITTSBURGH TESTING LABORATORY.

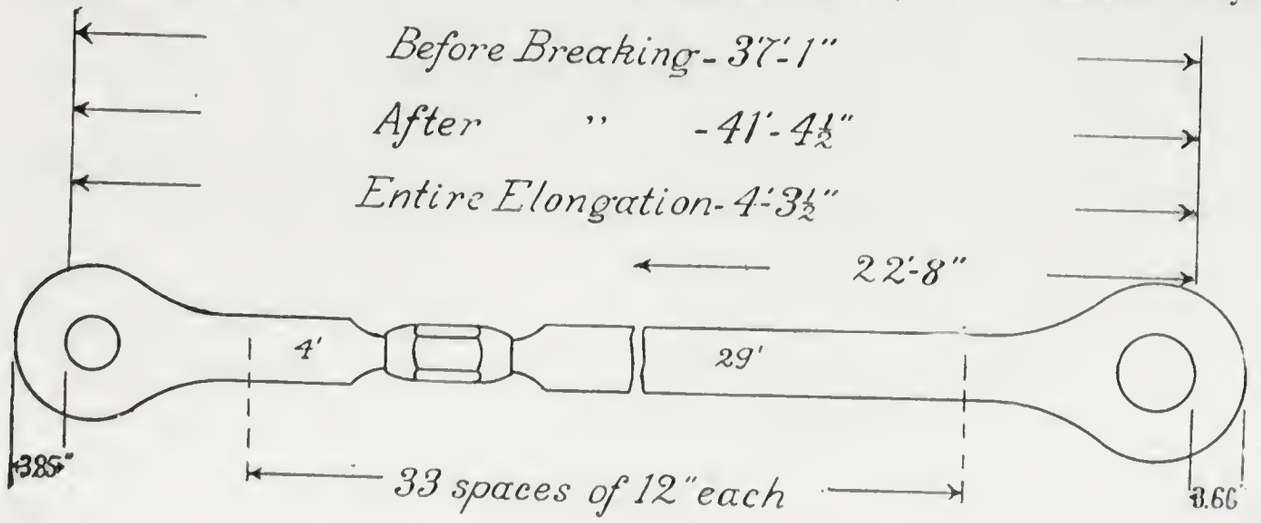
Report of Full-sized Test of Steel Eye-Bar Manufactured by Edgemoor Bridge Works. Bar Rolled by Cambria. Eye-Bar Tested August 28, 1891.

Results of Specimen Tests of Same Material.	Elastic Limit, lbs. per sq. in.	Tensile Strength, lbs. per sq. in.	Elongation, per ct. in 8 in.	Reduction of Area, per ct.	Character of Fracture in Tensile Test.	Cold Bending Test.	Nick Bending Test at 60° F.

Results of Eye-Bar Test.	Elastic Limit, lbs. per sq. in.	Tensile Strength, lbs. per sq. in.	Elongation, per ct. in 33 feet.	Reduction of Area, per ct. at Fracture.	Character of Fracture in Tensile Test.
	39,370	61,620	12.66	48.08	silky cup

Greatest Reduction of Area at Fracture.
Greatest Elongation in 12 inches at Fracture.

Elongation in 12 inches, including Fracture, 4.00″=33.33 per cent.
Location of Break, 22′ 8″ from back of eye. (B.)



A. Head.

Dimensions, 11.67″x.90″.
Excess, 2.45=55.30 per ct.
Diam. of Pin-Hole, 4.03″.
Elongation of Pin-Hole, 6.70 per ct.

B. Head.

Dimensions, 13.23″x .90″.
Excess, 2.04=46.05 per ct.
Diam. of Pin-Hole, 6.04″.
Elongation of Pin-Hole, 14.57 per ct.

Elongation in 33 feet, 4′ 2⅛″.
Nominal Section, 5″x ⅞″. Actual Section, 4.98″x .89″. Original Area, 4.43 sq. inches. Fractured Area, 3.84″x .60″=2.30 sq. inches.
Gauge Reading at Elastic Limit, 1,150. 174,397 Pounds Actual Elastic Limit of the Bar.
Gauge Reading at Tensile Strength, 1,800. 272,970 Pounds Actual Tensile Strength of the Bar.

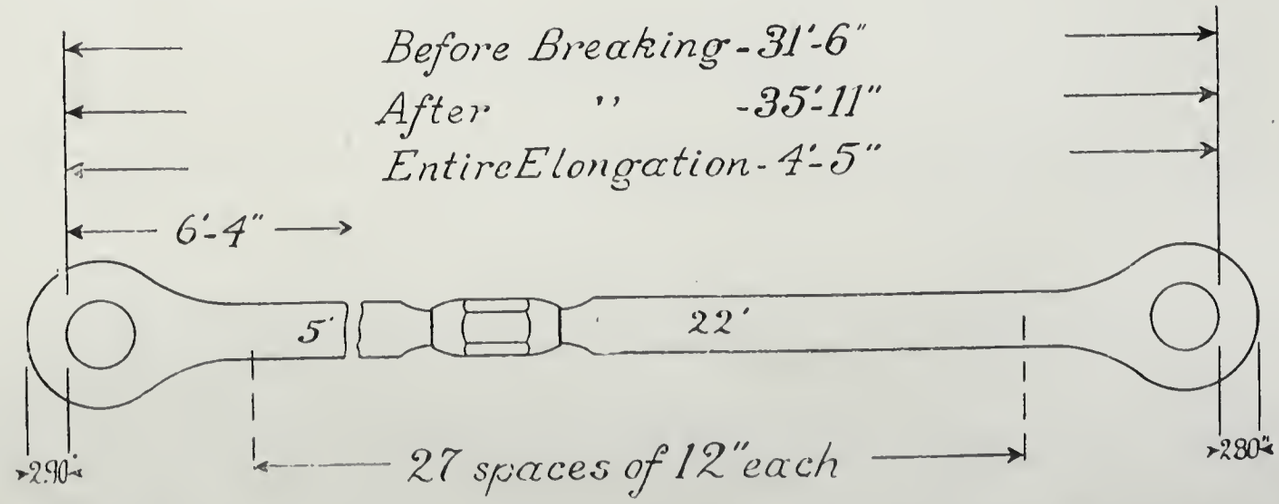
PITTSBURGH TESTING LABORATORY.

REPORT OF FULL-SIZED TEST OF STEEL EYE-BAR MANUFACTURED BY EDGEMOOR BRIDGE WORKS.
BAR ROLLED BY CAMBRIA. EYE-BAR TESTED OCTOBER 7, 1891.

	Elastic Limit, lbs. per sq. in.	Tensile Strength, lbs. per sq. in.	Elongation, per ct. in 8 in.	Reduction of Area, per ct.	Character of Fracture in Tensile Test.	Cold Bending Test.	Nick Bending Test at 60° F.
Results of Specimen Tests of Same Material.	37,530	60,330	30.00	60.00	silky cup		
	Elastic Limit, lbs. per sq. in.	Tensile Strength, lbs. per sq. in.	Elongation, per ct. in 27 feet.	Reduction of Area, per ct. at Fracture.	Character of Fracture in Tensile Test.		
Results of Eye-Bar Test.	37,700	59,240	15.63	51.42	silky cup		

Greatest Reduction of Area at Fracture.
Greatest Elongation in 12 inches at Fracture.

Elongation in 12 inches, including Fracture, 3.625″—30.21 per cent.
Location of Break, 6′ 4″ from back of eye. (A.)



A. HEAD.

Dimensions, 10.90″x .88″.
Excess, 1.49=42.33 per ct.
Diam. of Pin-Hole, 5.21″.

B. HEAD.

Dimensions, 10.90″x .90″.
Excess, 1.60=45.45 per ct.
Diam. of Pin-Hole, 5.21″.

Elongation of Pin-Hole, 5.90″=13.24 per ct.
Nominal Section, 4″x $\frac{7}{8}$″. Actual Section, 4.00″x .88″.
Gauge Reading at Elastic Limit, 875.
Gauge Reading at Tensile Strength, 1,375.

Elongation in 27 feet, 4′—$2\frac{5}{8}$″.
Original Area, 3.52 sq. inches.

Elongation of Pin-Hole, 5.80″=11.32 per ct.
Fractured Area, 3.00″x .57″=1.71 sq. inches.
132,693 Pounds Actual Elastic Limit of the Bar.
208,518 Pounds Actual Tensile Strength of the Bar.

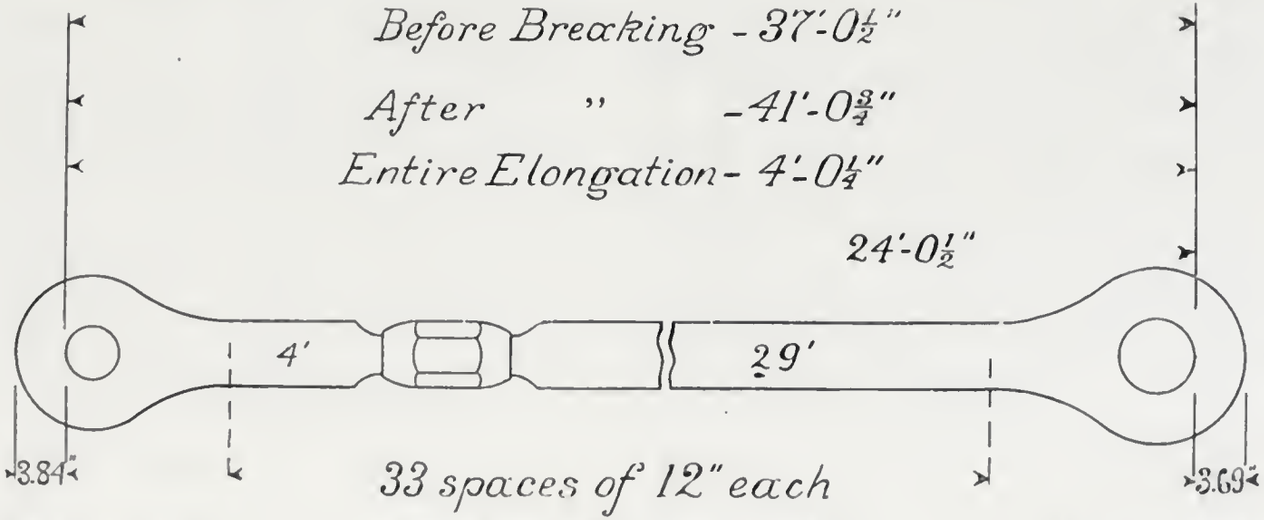
PITTSBURGH TESTING LABORATORY.

REPORT OF FULL-SIZED TEST OF STEEL EYE-BAR MANUFACTURED BY EDGEMOOR BRIDGE WORKS.
BAR ROLLED BY CAMBRIA. EYE-BAR TESTED AUGUST 8, 1891.

	Elastic Limit, lbs. per sq. in.	Tensile Strength, lbs. per sq. in.	Elongation, per ct. in 8 in.	Reduction of Area, per ct.	Character of Fracture in Tensile Test.	Cold Bending Test.	Nick-Bending Test at 60° F.
Results of Specimen Tests of Same Material.							
	Elastic Limit, lbs. per sq. in.	**Tensile Strength, lbs. per sq. in.**	**Elongation, per ct. in 33 feet.**	**Reduction of Area, per ct. at Fracture.**	**Character of Fracture in Tensile Test.**		
Results of Eye-Bar Test.	38,170	62,470	11.71	43.48	silky 45°		

Greatest Reduction of Area at Fracture.
Greatest Elongation in 12 inches at Fracture.

Elongation in 12 inches, including Fracture, 3.375″=28.13 per cent.
Location of Break, 13′ 0″ from back of eye. (A.)



A. HEAD.

Dimensions, 11.66″x .91″.
Excess, 2.58=59.04 per ct.
Diam. of Pin-Hole, 4.02″.

B. HEAD.

Dimensions, 13.13″x .91″.
Excess, 2.09=47.83 per ct.
Diam. of Pin-Hole, 6.03″.

Elongation of Pin-Hole, 9.45 per cent. Elongation in 33 feet, 3′ 10⅜″. Elongation of Pin-Hole, 13.60 per cent.
Nominal Section, 5″x ⅞″. Actual Section, 5.02″x .87″. Original Area, 4.37 sq. inches. Fractured Area, 3.86″x .64″=2.47 sq. inches.
Gauge Reading at Elastic Limit, 1,100. 166,815 Pounds Actual Elastic Limit of the Bar.
Gauge Reading at Tensile Strength, 1,800. 272,970 Pounds Actual Tensile Strength of the Bar.

TABLE V. (Summary of tests, pages 35, 36, 37.)

TESTS AT EDGEMOOR BRIDGE WORKS OF STEEL EYE-BARS WITH UPSET SCREW ENDS.

Eye-Bars.	Size.	Length.	Elastic Limit.	Ultimate Strength.	Elongation, per cent.	Reduction, per cent.	Remarks.
No. 1	5″ x $\frac{7}{8}$″	37′ 1″	39,370	61,620	12.66 (33′)	48.08	Broke in long end.
No. 2	4″ x $\frac{7}{8}$″	31′ 6″	37,700	59,240	15.63 (27′)	51.42	Broke in short end.
No. 3	5″ x $\frac{7}{8}$″	37′ 0½″	38,170	62,470	11.71 (33′)	43.48	Broke in long end.

These tests are certainly crucial tests, as it would be impossible to imagine a more difficult upset than to put a round screw end on a 5 x $\frac{3}{4}$ bar. Through the courtesy of the Edgemoor Bridge Works, I am also able to present to the Club this evening for examination a steel stirrup hanger. Not long ago one of the leading Southwestern railroads desired to renew a large number of hangers, which were necessarily limited in size because of the place they had to fit.

In connection with this, Mr. Henry G. Morse, member of the Club, and President of the Edgemoor Bridge Works, had some experimental tests of steel hangers made, and this is one of the hangers tested. The results of three tests are given in the table below.

TABLE VI.

TESTS AT EDGEMOOR BRIDGE WORKS OF STIRRUP HANGERS AND UPSET RODS.

Stirrup Hangers.	Diam. of Bar.	Root of Thread.	Area. Orig.	Area. Fract.	Elastic Limit.	Ultimate Strength.	Elong. in 12″, per et.	Reduction of Area, per cent.	Remarks.
No. 1	1.75	1.81	2.41	1.23	38,540	59,780	26.2	48.96	Broke in one leg, 1′ 3½″ from end.
No. 2	1.75	1.81	2.41	1.09	37,760	58,990	20.33	54.72	Broke in bend.
No. 3	1.75	1.81	2.41	.95	37,760	58,210	15.17	60.58	Broke in bend.
Upset Rods.									
No. 1	1.75	1.81	2.41	1.91	34,610	55,060	16.67	20.75	Broke 2′ 9$\frac{11}{16}$″ from end.
No. 2	1.75	1.81	2.41	2.06	40,900	56,630	11.67	14.52	Broke 2′ 5$\frac{1}{4}$″ from end.
No. 3	1.75	1.81	2.41	.99	37,760	58,210	33.33	58.92	Broke.

The material which was put in the hangers was taken from stock, being ordinary steel rounds which had been ordered for cotter pins. Your attention is called to the fact that the excess in area at the root of the thread on these hangers was but 7 per cent., and it may well be doubted whether iron hangers could have stood as severe a test. I have also here this evening some specimens of punched and rammed pieces which have been tested to destruction.

TABLE VII.

Details of Punched Tests Given in Tables III. and IV. for Soft and Medium Steel.

Thickness.	Specimen cut from	Elastic Limit, lbs. per sq. in.	Ultimate Strength, lbs. per sq. in.	Stretch in 8 in., per cent.	Stretch of Hole, per cent.	Character of Fracture.	Class of Steel.	
1/4″	7″ x 1/4″ Bess.	58,840	64,230	8.50	46.9	silky	soft steel	riveted holes.
5/16″	8″ x 5/16″ "	50,780	59,600	8.00	40.8	"	" "	" "
5/16″	8″ x 5/16″ "	54,080	70,460	5.75	29.6	"	medium steel	" "
3/8″	15″ x 3/8″ "	51,620	61,220	7.50	36.4	"	soft steel	" "
3/8″	4″ x 3″ x 3/8″ "	38,170	50,330	7.25			" "	open "
3/8″	7″ x 3/8″ "	40,610	54,260	9.50			medium steel	" "
1/2″	12″ x 1/2″ "	47,450	48,960	4.75	34.0	20 per ct. gran.	soft steel	" "
1/2″	14″ x 1/2″ "	45,550	66,190	7.00	32.6	silky	medium steel	riveted "
1/2″	6″ x 6″ x 1/2″ O. H.	33,950	63,540	7.50			" "	open "
9/16″	19 1/2″ x 9/16″ Bess.	38,950	52,400	7.50	48.9	silky	soft steel	" "
9/16″	12″ x 9/16″ O. H.	35,340	58,890	8.75			" "	" "
19/32″	18″ x 19/32″ Bess.		45,080	.38	3.09	granular	" "	" "
5/8″	14 1/2″ x 5/8″ "		43,820	.62	4.25	"	" "	" "
21/32″	10 1/4″ x 21/32″ O. H.	48,300	56,690	1.75	7.22	"	medium steel	riveted "
11/16″	8″ x 11/16″ Bess.	44,170	45,500	3.50	23.4	70 per ct. gran.	soft steel	open "
3/4″	18″ x 3/4″ "	40,070	41,180	.75	6.38	granular	" "	" "
3/4″	6″ x 6″ x 3/4″ O. H.	45,100	52,300	1.50	7.22	"	medium steel	riveted "
3/4″	" " "	45,970	53,300	1.35	5.15	"	" "	" "

SPECIFICATIONS FOR FIRST-CLASS BRIDGE SUPERSTRUCTURE.

GENERAL DESCRIPTION.

Materials.

1. All parts of the structure, except ties and guard-rails, and bed-plates of stringers, shall be of wrought iron or steel. Stringer beds will be cast iron. Cast iron or steel for other purposes will only be used for special conditions at the discretion of the Chief Engineer.

Ties and guard-rails.

2. Ties and guard-rails shall be of wood. They will be supplied by the railway company, but must be put in place by the contractor, who will also furnish all bolts, nuts, washers, etc. (except rail spikes), for this purpose.

Ties on tangents will be 8 inches by 10 inches, laid on 8-inch face and spaced 14 inches between centers; guard-rails will be 7 inches by 8 inches, spaced 8 feet between centers.

On curves the outer rail will be elevated $\frac{1}{2}$ inch per degree, and this elevation will be framed in the ties, as no shims will be allowed.

Ties will be notched $\frac{3}{4}$ inch over stringers, and guard-rails $\frac{3}{4}$ inch over ties.

Guard-rails will be bolted to each end of every other tie; and ties and guard-rails will be secured to stringers by hook bolts at each end of every fourth tie.

Superstructure.

3. For spans of 16 feet or less, rolled beams will be used, and from 16 feet to 100 feet, riveted plate girders. All spans over 100 feet will be pin-connected trusses.

Stringer-spacing

4. Beams or deck girders on masonry will be spaced 7 feet 0 inches center to center (ties 10 feet long). Riveted stringers on through single-track bridges and on trestles will be spaced 9 feet center to center (ties 12 feet long), beam stringers, 8 feet 6 inches; on double-track through bridges, 7 feet center to center, symmetrically disposed under the rails.

Tracks will be 13 feet apart center to center.

Clearance for through spans.

5. Through bridges on tangents shall not be less than 14 feet in width in the clear between trusses for single track, and 27 feet for double track, nor less than 20 feet in height in the clear, measuring from base of rail to the lowest point of portals.

Trusses on curves.

6. On curves the truss on the convex side will be 7 feet from the center line at the middle of the span; at the ends of the span the truss on the inner side of curve will be spaced 7 feet $+ 0.2\,d$ feet from the center line, d being the degree of curve.

The case of a curve near enough to a bridge to require elevation of the rail will also be considered and provided for.

Deck trusses.

7. Deck truss bridges on tangents will be spaced at least 10 feet center to center of trusses.

Through girders.

8. Through plate girders will be spaced at least 13 feet 6 inches center to center on tangents.

Girders on curves.

9. Stringers, deck girders and deck truss spans on curves will be spaced as may be necessary to suit the circumstances and to satisfy the Engineer.

Design.

10. All structures will be simple in design, and admit of accurate calculation of the stresses in each member.

11. Pin trusses will be in all ordinary cases of the single intersection type with leaning end-posts.

Collision strut.

12. All end-posts of through pin spans will be braced by collision struts, and the end-panels of the bottom chord and the vertical suspenders will be stiff members.

PROPOSALS.

13. Proposals for bridge work will be submitted on invitation of the Chief Engineer, and must conform with these specifications, with general plans or descriptions furnished by the Engineer, and with other conditions provided for in the letter of invitation.

Plans, etc.

14. Complete strain sheets, general plans of structure, and detail drawings, shall be furnished to the Chief Engineer of the railway company without charge.

Strain sheets

The strain sheets must show for each member the maximum stress or stresses caused by the dead load, the live load and the wind separately: the unit strains and the dimensions and areas of cross-sections. Also the dead weight assumed in the calculation, which must not be less than the actual weight of the structure as built.

15. It will be noted that the specifications below provide as follows:

Grade of material used.

(1) That all eye bars and pins shall be of medium steel (see §§ 133 and 146).

(2) That all web plates shall be of steel (see § 76).

(3) That loop rods and all other devices which are welded shall be of wrought iron.

These requirements, as defined below, are common to all bridges, whether built of wrought iron, soft steel or medium steel. The other parts of bridges, however, may be built of such grades of material as the contractor may elect, provided only that each member and each set of members performing similar functions must be of the same grade of material throughout.

Approval of plans and details.

16. Complete detail drawings must be submitted for approval to the Chief Engineer, and work will not be commenced until the stresses and details have been approved. He or such assistants as he may appoint shall have free access at all times to the working drawings and shops of the contractor for the purpose of examining the plans and inspecting the material used and the mode of construction.

17. The contractor shall furnish to the Chief Engineer of the railway company, free of cost, such detail drawings of each structure as he may require.

LOADING.

LIVE LOADS.

18. Live loads will be as per diagram furnished by the Chief Engineer.

19. The structure will be proportioned to carry the live loads as per diagram, and the live load stresses will be the maximum stresses produced by the rolling load considered as stationary or as moving in either direction. In double-track structures, one track or both will be considered loaded, whichever may produce the greater stresses, and the trains will be supposed to move either in the same or in opposite directions.

DEAD LOAD.

20. The dead load shall consist of the entire structure, including the floor-system and rails and fastenings. The weight of the ties, guard timbers, rails, spikes, etc., shall be taken at 400 pounds per lineal foot for each track.

The load of the structure when complete shall not exceed the dead load used in calculating the stresses.

21. In through bridges, two-thirds ($\frac{2}{3}$) of the dead load shall be assumed as concentrated at the joints of the bottom chord, and one-third ($\frac{1}{3}$) at the joints of the upper chord.

In deck bridges, two-thirds ($\frac{2}{3}$) of the dead load shall be assumed as concentrated at the joints of the upper chord, and one-third ($\frac{1}{3}$) at the joints of the bottom chord.

WIND IN TRUSSES.

22. The bottom lateral bracing in deck bridges and the top lateral bracing in through bridges must be proportioned to resist a uniformly distributed lateral force of 150 pounds per lineal foot of bridge for all spans of 200 feet and under, and an additional force of 10 pounds per lineal foot for every 25 feet increase in length of span over 200 feet.

23. The bottom lateral bracing in through bridges and the top lateral bracing in deck bridges must be proportioned to resist a uniformly distributed force the same as above, and an additional force of 300 pounds per lineal foot of bridge, which will be treated as a moving load.

WIND IN TRESTLES.

24. Trestles shall be so proportioned, and the trestle bents shall have such a spread of base, that no tension may occur in the windward trestle-leg when the structure is loaded with a light train weighing 600 pounds per lineal foot of track, and when the wind pressure on this train is 300 pounds per lineal foot, acting 9 feet above the rail. In addition, the wind pressure on the structure itself shall be assumed at not less than 150 pounds for each longitudinal foot of structure, and not less than 100 pounds for each vertical foot of height of each trestle bent, and more if the exposed wind surface of track and structure exceeds 5 square

feet for each foot in length, and the exposed wind surface of each trestle bent exceeds 3½ square feet for each vertical foot of height.

In all cases the projected surface of both sides of the towers and of one train is to be taken as the surface acted upon by the wind.

CENTRIFUGAL FORCE.

25. When the bridge is on a curve add to the maximum wind stresses a moving lateral stress equal to 3 per cent. of the live load on all tracks (acting in the direction of centrifugal force) for each degree of curvature.

26. The effects of wind and centrifugal force in the lateral system of structures must be fully provided for at unit stresses given below.

LONGITUDINAL BRACING AND ANCHORAGE.

27. Longitudinally the bracing of trestle towers and the attachments of the fixed ends of all trusses shall be capable of resisting the greatest tractive force of the engines or any force induced by suddenly stopping the assumed maximum trains, the coefficient of friction of the wheels upon the rails being assumed to be 0.20.

Double-track structures will be braced to provide for trains moving either in the same or in opposite directions.

TEMPERATURE.

28. Variations in length from change of temperature to the amount of 1 inch in 100 feet shall be provided for.

CALCULATIONS AND UNIT STRESSES.

29. All parts of the structure will be proportioned to sustain the maximum stresses produced by the live and dead loads specified above, and by the wind and centrifugal forces under special conditions provided in paragraphs 26, 32 and 39.

Assumed spans.

30. In calculating strains, conventional assumptions will be used throughout. The lengths of spans will be the distance between centers of end-pins of trusses, and between centers of bearing plates of beams and girders.

Assumed lengths, etc.

The length of stringers will be the distance between centers of floor beams, and the length of floor beams the distance between centers of trusses.

The depth for calculation of girders will be the distance between centers of gravity of flange sections, provided it does not exceed the distance out to out of angles, in which case the latter amount shall be considered the depth.

The length of posts will be the center to center length between pins, except in trestle-posts, where the length will be from cap or base plate to the centers of intermediate struts.

In estimating the section of end-posts, the collision-strut connection will not be considered.

Any modification of this will be at the discretion of the Engineer.

Bending in pins and rivets will be estimated between centers of bearings.

FORMULÆ FOR UNIT STRAINS.

31. The following formulæ for unit strains per square inch of net sectional area shall be used in determining the allowable working stress in each member of the structure:

TENSION MEMBERS.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
(*a*) Floor-beam hangers or suspenders, forged bars	Will not be used.	Will not be used.	7,000
Counter ties	6,000	" " "	7,000
Suspenders, hangers and counters, riveted members, net section (see § 140)	5,000	5,500	7,000
(*b*) Solid rolled beams (by moments of inertia)	8,000	8,000	Will not be used.
(*c*) Riveted truss members and tension flanges of girders, net section. See § 82.	$7{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)$	8 % greater than iron.	$9{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)$
Forged eye-bars	Will not be used.	Will not be used.	$9{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)$
(*d*) Lateral or cross-section rods	15,000	16,000	For eye-bars only. 17,000.

COMPRESSION MEMBERS.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
(*e*) Chord sections:			
Flat ends	$7{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)-30\frac{l}{r}$	10 % greater than iron.	20 % greater than iron.
One flat and one pin end	$7{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)-35\frac{l}{r}$	" " " "	" " " "
Chords with pin ends and all end-posts	$7{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)-40\frac{l}{r}$	" " " "	" " " "
(*f*) All trestle-posts	$7{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)-35\frac{l}{r}$	" " " "	" " " "
(*g*) Intermediate posts	$7{,}500-40\frac{l}{r}$	" " " "	" " " "
(*h*) Lateral struts, and compression in collision struts, stiff suspenders and stiff chords	$10{,}500-50\frac{l}{r}$	" " " "	" " " "

In which formulæ, l = length of compression member in inches, and r = least radius of gyration of member in inches. If the allowable stresses given by formula (*c*) are less than those given by (*e*), (*f*) and (*g*), the former will be used.

MEMBERS SUBJECT TO ALTERNATE TENSION AND COMPRESSION.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
(*i*) For compression only	Use the formulæ above.		
For the greatest stress	$7{,}000\left(1-\frac{\text{max. lesser.}}{2\text{ max. great'r}}\right)$	8 % greater than iron.	20 % greater than iron.

Use the one giving the greatest area of section.

(*j*) The compression flanges of beams and plate girders will have the same cross-section as the tension flanges.

COMBINED STRESSES.

(*k*) When the cross-ties rest directly on the top chords, the latter will be considered as beams of one panel length, subject to the maximum bending that will result from the wheel loads and floor system, the beam to be considered as supported at the ends for section in center of panel, and fixed at the ends for section at the ends of panel. The chords will be proportioned to sustain the algebraic sum of the stresses resulting from the direct compression or tension and the transverse loading given above, in which the allowed stress per square inch shall not exceed:

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
At center of panel	8,000	8,800	9,600
At ends of panel	10,000	11,000	12,000

SHEARING.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
(*l*) On pins and shop rivets	6,000	6,600	7,200
On field rivets	4,800	5,200	Will not be used.
In webs of girders	Will not be used.	5,000	6,000

BEARING.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
(*m*) On projected semi-intrados of main pin holes	12,000	13,200	14,500
On projected semi-intrados of rivet holes	12,000	"	"
Excepting that in pin-connected members taking alternate stresses, the bearing stress must not exceed 9,000 *pounds for iron or steel.*			
On lateral pins	15,000	16,500	18,000
Of bed-plates on masonry	250 pounds per square inch.		

BENDING.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
(*n*) On extreme fibers of pins when centers of bearings are considered as points of application of strains	15,000	16,000	17,000

(*o*) COEFFICIENTS OF FRICTION will be used as follows:

Wrought iron or steel on itself	.15
" " " cast iron	.20
" " " masonry	.25
Masonry on itself	.50

Effects of wind in truss members.

32. In case the maximum stresses in chords, girder flanges, trestle-posts, or the bending effects on posts due to wind or centrifugal force, shall exceed 25 per cent. of stresses due to dead and live load, the sections will be increased until the total strain per square inch will not exceed by more than 25 per cent. the maximum fixed for live and dead load only.

Collision struts.

33. Collision struts will be proportioned to carry a thrust of 50,000 pounds acting in a direction at right angles to the end-post.

Stiff suspenders.

Stiff suspenders must be able to carry a compressive stress equal to six-tenths ($\frac{6}{10}$) the maximum tensile stress.

Stiff chords.

Stiffened chords will be proportioned to take compression equal to $60\frac{T}{L}$, in which T is the maximum tension in pounds in the chord, and L is the span in feet. Use formula (h) for these members.

Bending due to weight of member.

34. The effects of the weights of horizontal or inclined members in reducing their strength as columns must be provided for. It will also be considered in fixing the position of pin centers.

Flange areas of girders.

35. Plate girders shall be proportioned upon the supposition that the bending or chord strains are resisted entirely by the upper and lower flanges, and that the shearing or web strains are resisted entirely by the web plate.

Value of rivets.

36. The effective diameter of the driven rivet shall be considered the same as the diameter before driving.

Deducting rivet holes.

In deducting for rivet holes, the diameter of the hole will be considered $\frac{1}{8}$ inch greater than the rivet for full-headed rivets, and $\frac{1}{4}$ inch larger for countersunk rivets.

Minimum compression members.

37. No compression member shall have a length exceeding 45 times its least width, and no post will be used in which $\frac{l}{r}$ exceeds 125.

Camber.

38. All bridges with parallel chords shall be given a camber by making the panel lengths of the top chord longer than those of the bottom chord in the proportion of $\frac{1}{8}$ inch to every 10 feet.

Initial strain.

39. An addition of 10,000 pounds must be made to the stress obtained in all lateral rods to provide for initial tension, and the proper component of this total stress is to be used in the calculation of all lateral struts.

DETAILS OF CONSTRUCTION AND WORKMANSHIP.

GENERAL.

40. All details must be of approved forms and satisfactory to the Chief Engineer.

41. Preference will be had for such details as will be most accessible for inspection, cleaning and painting.

Minimum sections.

42. No shape iron weighing less than 6 pounds per lineal foot will be used, nor any iron less than $\frac{3}{8}$ inch thick, nor any bar of less than one square inch section.

No angle smaller than 3 inches by 3 inches will be used in girders or truss members, or in any member having $\frac{7}{8}$ inch rivets.

No angle smaller than $2\frac{1}{2}$ inches by $2\frac{1}{2}$ inches will be used in any part of bridge structures.

End angles carrying stringers and floor beams will be at least $\frac{1}{2}$ inch thick (see ℔ 60 and ℔ 101).

43. All bed-plates will be at least $\frac{3}{4}$ inch thick.

Tension bars.

44. No tension bar will be less than 1 inch thick, and all tension bars will be of rectangular section.

No eye-bars over 2 inches thick will be used; the maximum size of eye-bars will be 8 inches by 2 inches.

Pins.

45. No main pins will be less than $3\frac{1}{2}$ inches diameter, nor less in diameter than three-quarters of the width of the widest bar attaching to them.

46. Angles, cover plates and web sheets shall be as long as practicable to avoid splicing.

Universal plates

Plates for all purposes shall be universal-rolled when the width does not exceed 30 inches. (See §§ 76, 78, 124.)

Pitch of rivets.

47. The pitch of rivets will not be less than 3 diameters, nor more than 6 inches (see § 92), nor more than 16 times the thickness of the thinnest outside plate. No rivet will have a longer grip than 5 times its diameter, nor be nearer the edge of the metal, through which it passes, than $1\frac{1}{4}$ inches when the edges are machine or roll-finished, *and will not be nearer than* $1\frac{3}{4}$ *inches to a sheared edge.*

48. The unsupported width of any plate subjected to compression shall never exceed 30 times its thickness, excepting cover plates of top chords and end-posts, where it may be 40 times its thickness.

49. Lattice bars will be as described in § 122.

50. All workmanship must be first class; the several pieces forming a built-up member must fit snugly together without open joints. This will be specially insisted upon with reference to pin-bearing chords and end-posts.

All members must be straight and out of wind; holes accurately bored both in position and direction; lengths correct within $\frac{1}{32}$ inch in all cases and within $\frac{1}{50}$ inch for all pieces of the same set.

51. Work will be designed in clean, handsome lines. In addition to the value and usefulness of members in the structure, they will be neatly finished.

52. All material must be straightened before being laid off, and also after punching, if necessary.

I-BEAM SPANS.

53. I-beam stringers on masonry will preferably be double under each rail, spaced 7 feet 0 inches between centers of bed-plates.

54. They will have planed sole plates riveted to the flanges, and bolted through bed-plates to the masonry at one end, and free to slide longitudinally at the other. They will have rigid cross-struts and transverse bracing riveted to the webs.

55. When in pairs, they will have wrought metal separators.

56. Bed-plates will be cast iron, 3″ high.

57. All holes in flanges will be drilled. Holes in webs may be punched.

58. I-beam stringers between floor beams will preferably be in single

I-beam stringers

lines under each rail, and will have lateral bracing between webs for all spans over 12 feet.

59. They will be spaced 8 feet 6 inches between centers, and be riveted to webs of floor beams.

Hitch angles.

60. The angles carrying them at the ends will be either 4 inches by 4 inches by $\frac{1}{2}$ inch, or 6 inches by 6 inches by $\frac{1}{2}$ inch.

61. If resting on top of floor beams, they will be riveted to the floor beams, and knee-braces will support both ends of each line of beams.

62. On the abutments, they will have cross-struts, and be stayed to the main shoes of girders or trusses. Sole plates and bed-plates (see §§ 54 and 56).

Milled ends.

63. Beams fitting between floor beams must be milled to length and have the hitch angles accurately set, square to the stringer and flush with its end.

64. Beams which are not required to be of exact length may vary $\frac{1}{4}$ inch from dimensions called for and may have the ends cut by cold saw.

65. Heating beams to cut them will not be allowed, and no patched beams will be received.

RIVETS.

66. Rivets will be $\frac{3}{4}$ inch or $\frac{7}{8}$ inch diameter in the rod before upsetting.

67. For main members $\frac{7}{8}$-inch rivets will preferably be used, with $\frac{3}{4}$-inch rivets for lateral members.

68. Rivets will be power-driven wherever practicable, and must have full round heads concentric over the shank of the rivet.

69. Whenever the grip length of rivet exceeds $2\frac{1}{2}$ inches, power-driven rivets will be insisted upon.

70. All rivet holes will be accurately laid off and punched.

71. The dies will not exceed the diameter of rivet by more than $\frac{1}{16}$ inch.

72. When the several pieces forming a member are bolted up, the holes must match accurately throughout, or the material may then be condemned.

73. No drifting will be allowed; holes requiring it must be reamed; hot rivets must enter the holes without the use of a hammer.

74. Countersinking will be neatly done, all holes of the same size, and countersunk rivets must completely fill the holes.

75. Rivets must completely fill the holes, and no loose or badly formed rivets will be allowed, nor any caulking. Field riveting must be reduced to a minimum.

PLATE GIRDERS.

Steel webs.

76. The webs of all plate girders will be of steel (see Quality of Material, § 171 to § 184).

Universal plates will be used for widths up to 30 inches, and sheared plates for greater widths.

77. No rivet holes will be pitched *nearer than* $1\frac{3}{4}$ *inches to a sheared edge*, or nearer than $1\frac{1}{4}$ to a roll-finished or machined edge of the webs.

78. Web splices will be made by two universal steel plates of the same thickness as the web plate.

Stiffeners will be used at all web splices.

The width of the splice plates shall be sufficient to admit the requisite number of rivets and to receive the stiffeners.

79. Wherever the unsupported distance between the flange angles exceeds 50 times the thickness of the web sheet, vertical stiffeners of angle iron shall be placed on each side of the girder.

Stiffeners.

Stiffeners will be symmetrically spaced from the center of the girder, and the distance between them, center to center of rivets, will not be greater than the distance between centers of flange angles. If unequally spaced, the distance between them will decrease toward the ends.

80. There will be a pair of stiffeners at each end of all bed-plates.

Fillers.

81. All stiffeners will have fillers under them of the same thickness as flange angles and as wide as stiffener angles.

82. The net section of tension flanges will be reckoned as the minimum section square across the flange, and the net section on any diagonal or broken line through two or more rivet holes must have 25 per cent. excess.

83. In calculating shearing and bearing strains on web rivets of plate girders, the maximum shear acting on the outer side MM of any panel will be considered to be transferred to the flange angles in a distance, MO (equals MM), and the number of rivets in the stiffener MM will follow the same rule.

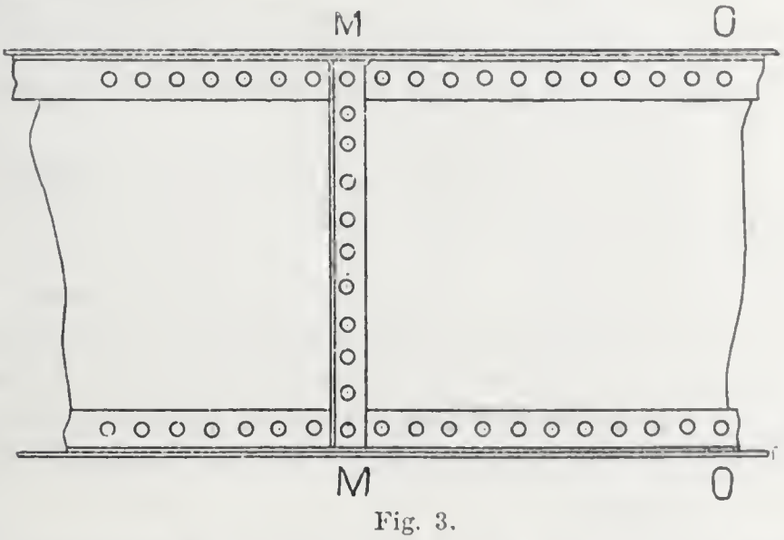


Fig. 3.

Fit of stiffeners, etc.

84. All stiffeners, fillers and splice plates on the webs of girders must fit at their ends to the flange angles sufficiently close to be sealed, when painted, against admission of water, but need not be tool-finished.

85. Web plates of all girders must be arranged so as not to project beyond the faces of the flange angles, nor on the top be more than $\frac{1}{16}$ inch below the face of these angles at any point.

Rivet spacing for local shear.

86. To provide for local shear of heavy wheel loads, the rivet spacing in top flanges of deck-plate girders and stringers will not exceed 3 inches pitch, when there are no cover plates, or 4 inches with cover plates.

Lateral bracing.

87. The compression flanges of girders will be stayed at intervals not exceeding 15 times their width.

88. In through spans, stiffened gussets will run from top flange to each floor beam.

89. In deck spans the lateral bracing will extend from end to end, and no brace will make an angle less than 40 degrees with the girders, excepting end braces of skew spans.

One top flange plate, etc.

90. All girders having flange plates will have one plate in each flange extending from end to end; and, with the exception of floor beams, girders will preferably have at least one flange plate.

91. When two or more plates are used on the flanges they shall either be of equal thickness or shall decrease in thickness outward from the angles, and shall be of such lengths as to allow of at least two rows of rivets of the regular pitch being placed at each end of the plate beyond the theoretical point required.

92. When two or more cover plates over 12 inches wide are used in the flanges of plate girders, an extra line of rivets shall be driven along each edge to draw the plates together and to prevent the entrance of water.

Plates over 17 inches wide will have three rows of rivets with 9 inches pitch for the outer row.

Flange splices.

93. All joints in flanges, whether in tension or compression members, must be fully spliced, as no reliance will be placed upon abutting joints. The ends, however, must be dressed straight and true, so that there shall be no open joints.

94. Flange angles must be spliced with angle covers whenever cut within the length of the girder.

95. Splices must break joints with each other, one piece only being spliced at any point.

Cross-frames.

96. Cross-frames will be used at the masonry ends of all girders and at intermediate points when wind or centrifugal force makes it desirable.

97. All cross-frames will be made of angles and plates, and will be stiff rectangles of four members, viz: top, bottom and two diagonals.

Finish of girders

98. Girders will be neatly finished at the ends. They will have a plate corresponding in width with the cover plates riveted to end stiffeners, and a corner cover at the top riveted to both top and end plates.

STRINGERS AND FLOOR BEAMS.

Steel webs.

99. Webs of stringers and floor beams will be steel (see § 76).

100. Stringers and floor beams will preferably be carried by rivets at their ends, and all such ends will be milled to exact length.

101. The end angles carrying floor beams and stringers will be either

$4 \times 4 \times \frac{1}{2}$, or $6 \times 4 \times \frac{1}{2}$, or $6 \times 6 \times \frac{1}{2}$ inch angles, as one or two rows of rivets are required, and they will have fillers under them 7 inches and 9 inches wide, respectively, of same thickness as flange angles, and having a row of rivets outside the hitch angles.

Hitch angles.

102. The hitch angles of stringers will have a full complement of rivets, and, in addition, stringers may have a bracket and stiffeners under them unless they practically cover the web of floor beam between flanges.

Reamed holes for field rivets.

103. All holes for field rivets in stringer and floor-beam connections will be punched $\frac{3}{4}$ inch diameter, and afterward reamed out to $\frac{13}{16}$ inch, using cast-iron templates. The wire edge on reamed holes must be removed.

104. Floor beams having stringers resting on their top flanges will have stiffeners under the points of support.

105. Stringers will preferably have one cover-plate from end to end (see § 90).

The rivet pitch through the web in top flanges of stringers will not exceed 4 inches throughout (see § 86).

Hangers.

106. Hangers will be either solid forged eye-bars riveted to floor beams, or riveted plate hangers. Stirrup hangers or bent hangers will not be used.

107. Eye-bar hangers will have the usual excess of material across the eye, and all rivet holes in them will be bored, and the edges of holes will be chamfered to make a fillet under rivet head.

108. All riveted hangers will have excess sections at the pin holes, as described in § 139.

LONG PLATE GIRDERS.

109. Plate girders of lengths from 75 ft. to 100 ft. may be built of medium steel, under special conditions, as follows:

110. All rivet holes in the angles and plates in both flanges will be drilled in the solid. Occasional small holes may be punched for purposes of bolting up and reamed afterward.

111. All other rivet holes in web plates, stiffeners, lateral braces and fillers may be punched of full size for riveting, provided the metal does not exceed $\frac{9}{16}$ inch thickness.

112. The spliced ends of tension flange plates or angles will be milled off $\frac{1}{4}''$ to remove sheared edges; and the ends of all splicing pieces in tension flange will be similarly milled. No other milling of sheared edges will be required, excepting such as is specified for iron girders.

113. All web splices will have four rows of rivets, the middle rows being pitched five inches between centers.

114. Rivets will be of soft steel and power-driven whenever practicable.

115. The general requirements given under plate girders will apply to these also, except as modified above. See §§ 77 to 98 inclusive.

PIN-CONNECTED SPANS.

116. See §§ 10, 11, 12, 31, 33 and 47.

117. No web member, except collision struts, shall make a less angle with the horizontal than 45 degrees.

COMPRESSION MEMBERS.

118. All parts working together as one member shall be uniformly stressed.

Center of gravity.

119. All eccentricity of stress shall be avoided. Pin-centers will be in the center of gravity of the members, less the eccentricity required to provide for their own weight; and in continuous chords, pin-centers must be in the same plane.

120. See §§ 46 and 69.

Batten plates.

121. The open sides of all compression members shall be stayed by batten plates at the ends, and diagonal latticework at intermediate points. The batten plates must be placed as near the ends as practicable, and shall have a length of $1\frac{1}{2}$ times the width of the member.

Lattice.

122. Lattice bars will preferably be of soft steel, and will be at least $2\frac{1}{2}$ inches wide for $\frac{3}{4}$-inch or $\frac{7}{8}$-inch rivets, and increase with the width of the member. They will make an angle of 60 degrees with the axis of the member, and the same angle or less with each other.

123. Double lattice will be used in all members having a clear width between webs of more than 20 inches.

Pin plates.

124. When necessary, pin holes shall be re-enforced by plates, so the allowed pressure on the pins shall not be exceeded. These re-enforcing plates must contain enough rivets to transfer their proportion of the bearing pressure, and at least one plate on each side shall extend not less than 6 inches beyond the edge of the furthest batten plate.

Pin, splice and batten plates will be universal-rolled plates.

Forked ends.

125. When the ends of compression members are forked to connect to the pins, the aggregate compressive strength of these forked ends must equal the compressive strength of the body of the members; in order to insure this result, the aggregate sectional area of the forked ends at any point between the inside edge of the pin hole, and 6 inches beyond the edge of the batten plate, shall be about double that of the body of the member.

126. In compression chord sections, the material must mostly be concentrated at the sides, in the angles and vertical webs.

Pin holes.

127. Pin holes shall be bored exactly perpendicular to a vertical plane passing through the center line of each member when placed in a position similar to that which it is to occupy in the finished structure.

Milled ends.

The ends of all members which make contact joints shall be planed smooth, to exact lengths and to exact angles, with the axis of the member.

Reamed splices.

128. Abutting members must be brought into close and forcible contact when fitted with splice plates, and the rivet holes reamed in position before leaving the works, all pieces being match-marked, so as to go in the same position in erecting.

Pitch of rivets at ends.

129. In all compression members the pitch of rivets at the ends shall not be over four times the diameter of the rivets for a length equal to twice the width of the member.

Couplers.

130. The couplers on chords and end-posts will be at least $\frac{1}{2}$ inch thick.

131. In intermediate posts, both web and pin plate will extend beyond the pin for a length about equal to the diameter of pin hole.

Collision struts.

132. Collision struts will be disposed to best advantage to take a shock of derailed train striking $3\frac{1}{2}$ feet above base of rail. They will preferably make an angle of 80 degrees or more with the end-post and may be placed 3 feet away from the point indicated above in order to increase the angle.

TENSION MEMBERS.

EYE-BARS.

133. All eye-bars will be solid forged steel bars of approved quality and rolled by mills having established reputations for the manufacture of eye-bar steel.

134. No work on the bars will be done at a blue heat, and all bars must be thoroughly annealed after forging.

135. The heads of eye bars shall be so proportioned that the bar will break in the body instead of in the eye. The form of the head and the mode of manufacture shall be subject to the approval of the Chief Engineer of the railway company before the contract is made.

136. The bars must be free from flaws and of full thickness in the necks. They shall be perfectly straight before boring. The holes shall be in the center of the head and on the center line of the bar.

137. The bars must be bored of exact lengths and the pin holes $\frac{1}{50}$ inch larger than the diameter of the pin.

All bars on the same item must be bored at one setting of the drills and at the same temperature.

Bars may vary $\frac{1}{32}$ inch from ordered length, but bars on the same item must not vary $\frac{1}{50}$ inch in length.

Rivet holes in eye-bars will be drilled, and have the wire edges cut off the edges of the holes.

Upset screw ends.

138. Upset screw ends may be used on steel bars if fully guaranteed and tested in full-sized bars. The area at base of thread and at all parts of upset ends will be 15 per cent. in excess of the area of the bar.

RIVETED TENSION MEMBERS.

Excess at pin holes.

139. Riveted tension members must be designed with special care. Members with pin connections will be required to have net areas across the pin hole, and back of the pin hole, respectively of 150 per cent. and 80 per cent. of the net area required in the body of the member, and there will be a corresponding excess of rivets to make this material effective.

The length from back of eye to end of member must be greater than the radius of the pin.

140. In members with riveted connections special care will be used to have the rivets symmetrically arranged from the center line and to avoid eccentricity of stress.

If rivets are straggered they will all be deducted as though they occurred at the same cross-section.

RODS.

141. Rods for counters or laterals will, preferably, be either simple loops or clevis rods.

142. Loop rods will be of wrought iron and must be upset and welded in a thoroughly efficient and workman-like manner.

143. The eyes of all loop rods must be bored to fit the pins.

Upset screw ends must have a net section at base of thread 15 per cent. greater than the body of the bar.

144. Steel rods may be used for upset screw ends, but will be fully guaranteed and tested in full-sized section. They must be annealed after forging.

145. Clevises, turn buckles and sleeve nuts must be of approved pattern and fully guaranteed.

PINS.

146. All main pins will be made of medium steel.

The diameter of the pin will not be less than three-fourths ($\frac{3}{4}$) the largest dimension of any tension member attached to it.

147. The several members attached to the pin shall be packed close together, and all vacant spaces between the chords and posts must be filled with wrought-iron filling rings.

The pins shall be turned straight and smooth, and shall fit the pin holes within $\frac{1}{50}$ inch. They shall be turned down to a smaller diameter at the ends for the thread, and driven in place with a pilot-nut when necessary to save the thread.

148. Nuts will be of wrought iron or wrought steel. There will be a washer under each nut, or else Lomas nuts will be used.

LATERAL BRACING.

149. The attachment of the lateral system to the chords shall be thoroughly efficient. If connected to suspended floor beams the latter shall be stayed against all motion.

150. Preference will be given to lateral bracing in the floor system, which is capable of resisting both compression and tension.

Portals and knee braces.

151. Portals and intermediate knee braces shall be used in all through bridges, so designed as to form efficient and rigid connection between top lateral struts and web members. Where the height of the truss makes it practicable, the knee-braces shall be replaced by suitable cross-section bracing at each pair of intermediate posts.

152. When brackets only can be used for portal braces they will have plate webs.

Portals will be as deep as the head room will allow.

Deck spans.

153. In all deck bridges transverse bracing shall be provided at each panel; this bracing shall be proportioned to resist the unequal loading of the trusses, and the wind and centrifugal forces; the transverse bracing at the ends shall be of the same equivalent strength as the end top lateral bracing.

154. The hitches for lateral braces must be thoroughly efficient; shear on field rivets will be reckoned as per formula (*l*).

SHOES, BED-PLATES, ETC.

155. There must be a pier box or plate of approved form under pedestal shoes at both ends, of sufficient depth to distribute the weight properly on masonry. These boxes or plates must be at least $\frac{3}{4}$ inch thick, must have planed surfaces and be of such dimensions that the greatest pressure upon the masonry will not exceed 250 pounds per square inch, and sheet lead not less than $\frac{1}{8}$ inch thick shall be interposed between them and the masonry.

Two spans.

156. Where two spans rest upon the same masonry a continuous plate not less than $\frac{3}{4}$ inch thick shall extend under the two adjacent bearings.

Bolts.

157. All the bed-plates and bearings under fixed and roller ends must be fox-bolted to the masonry; for trusses, these bolts must not be less than $1\frac{1}{4}$ inches diameter; for plate and other girders, not less than $\frac{7}{8}$ inch diameter. The contractor must furnish all bolts, drill all holes, and set bolts to place with sulphur.

Rollers.

158. All bridges over 75 feet span shall have at one end nests of turned friction rollers, formed of wrought steel, running between planed surfaces. The rollers shall not be less than $2\frac{1}{2}$ inches diameter, and shall be so proportioned that the pressure per lineal inch of roller shall not exceed the product of the square root of the diameter of the roller in inches multipled by 500 pounds ($500\sqrt{d}$). Bridges less than 75 feet span will be secured at one end to the masonry, and the other end shall be free to move by sliding upon planed surfaces.

No lateral movement.

159. Friction rollers must be so arranged as to be readily cleaned and to retain no water.

160. While the roller ends of all trusses must be free to move longitudinally under change of temperature, they shall be anchored against lifting or moving sideways.

WORKMANSHIP ON MEDIUM STEEL.

161. Medium steel will be subject to the general conditions given under "Workmanship" above, and in addition to the following requirements:

(*a*) All sheared and hot-cut edges shall have not less than $\frac{1}{4}$ inch

of metal removed by planing. (Lattice bars only will be exempted from this.)

(*b*) All punched holes will be reamed to a diameter $\frac{1}{4}$ inch larger, so as to remove all the sheared surface of the metal.

(*c*) No sharp or unfilleted re-entrant corners will be allowed.

(*d*) All rivets will be steel.

(*e*) Any piece which has been partially heated or bent cold will be afterward wholly annealed.

QUALITY OF MATERIAL.

WROUGHT IRON.

162. All wrought iron must be tough, ductile, fibrous and of uniform quality for each class, straight, smooth, free from cinder-pockets, flaws, buckles, blisters and injurious cracks along the edges, and must have a workman-like finish. No specific process or provision of manufacture will be demanded, provided the material fulfills the requirements of these specifications.

163. The tensile strength, limit of elasticity and ductility shall be determined from a standard test piece not less than $\frac{1}{4}$ inch thick, cut from the full-sized bar, and planed or turned parallel. The area of cross-section shall not be less than $\frac{1}{2}$ square inch. The elongation shall be measured after breaking on an original length of 8 inches.

164. The tests shall show not less than the following results:

	ULTIMATE STRENGTH.	LIMIT OF ELASTICITY.	ELONGATION IN 8 INCHES.
	POUNDS PER SQ. IN.	POUNDS PER SQ. IN.	PER CENT.
For bar iron in tension	50,000	26,000	18
" shape iron	48,000	26,000	15
" plates under 36 ins. wide	48,000	26,000	12
" " over " " "	46,000	25,000	10

165. When full-sized tension members are tested to prove the strength of their connections, a reduction in their ultimate strength of (500 × width of bar) pounds per square inch will be allowed.

166. All iron shall bend, cold, 180 degrees around a curve whose diameter is twice the thickness of piece for bar iron, and three times the thickness for plates and shapes.

167. Iron which is to be worked hot in the manufacture must be capable of bending sharply to a right angle at a working heat without sign of fracture.

168. Specimens of tensile iron upon being nicked on one side and bent shall show a fracture nearly all fibrous.

169. All rivet iron must be tough and soft, and be capable of bending cold until the sides are in close contact without sign of fracture on the convex side of the curve.

170. Samples from each rolling will be tested and also widely differing gauges of the same section.

STEEL.

171. All steel will be uniform in quality, low in phosphorus, and from works of established reputation.

Phosphorus.

172. The phosphorus in all melts of acid open-hearth steel must be less than 0.10 per cent., and in all Bessemer or basic steel must be less than 0.08 per cent. Certified analyses of all melts will be furnished the Engineer free of charge.

Tests from finished material.

173. The material will be tested in specimens of at least one-half square inch section, cut from the finished material. Each melt of steel will be tested, and each section rolled, and also widely differing gages of the same section.

174. If several different sections are rolled from the same melt of steel, all of them may be tested at the discretion of the inspector.

Melt numbers.

175. All finished material will be plainly and distinctly marked with correct melt numbers.

176. If the melt number is lacking, or is illegible, or has been changed, the material may be condemned at the discretion of the inspector.

Re-tests.

177. If first tests are unsatisfactory the material will not be accepted unless—

(1) A majority of the tests fill the specifications.

(2) All the tests show good material of reasonable uniformity.

SOFT STEEL.

178. Soft steel may be used under the same conditions as wrought iron except—

(1) It must be used consistently. The occasional use of pieces of steel will not be permitted.

(2) It must not be welded.

(3) The thickness of material subjected to punching will be limited to $\frac{1}{2}$ inch, excepting (*a*) in plate girders over 50 ft. long, in which it may be $\frac{9}{16}$ inch; (*b*) in top chords and end-posts, in which it may be $\frac{5}{8}$ inch; and (*c*) in shoes, pedestals and bed-plates, in which it may be $\frac{3}{4}$ inch thick.

179. Soft steel when tested as described above must meet the following requirements:

An elastic limit of at least 32,000 pounds per square inch.

An ultimate strength of 54,000 to 62,000 pounds per square inch.

An elongation in 8 inches of at least 25 per cent.

A reduction of area of at least 45 per cent.

Web plates.

For web plates over 36 inches wide the elongation will be reduced to 20 per cent. and the reduction of area to 40 per cent.

180. It must bend cold 180 degrees and close down on itself without cracking on the outside.

181. $\frac{7}{8}$-inch holes pitched $\frac{3}{4}$ inch from a roll-finished or machined edge and 2 inches between centers must not crack the metal; and

$\frac{7}{8}$-inch holes pitched $1\frac{1}{8}$ inch between centers and $1\frac{1}{2}$ inch from the edge must not split the metal between the holes.

Rivets. All rivets will be soft steel.

MEDIUM STEEL.

182. Medium steel only will be used for eye-bars and main pins, and it may be used for other members under conditions given in § 161.

183. Medium steel when tested as described above must meet the following requirements:

An elastic limit of at least 35,000 pounds per square inch.

An ultimate strength of from 60,000 to 70,000 per square inch.

An elongation in 8 inches of at least 20 per cent.

A reduction of area of at least 40 per cent.

It must bend 180 degrees on itself around a $1\frac{1}{2}$-inch round.

Eye-bar tests. 184. Full-sized eye-bars, when tested to destruction, must show an ultimate strength of at least 56,000 pounds, and stretch at least 10 per cent. in a gauged length of 10 feet.

There will be two bars tested from each span.

INSPECTION.

185. Ample facilities for inspection and testing of material and workmanship must be furnished to the Chief Engineer of the railway company or his assistants. Tests on small specimens to determine the quality of materials will be made free of charge to the railway company before any work is done on the material.

Full-sized tests. 186. Full-sized parts of the structure may be tested at the option of the Engineer of the railway company, and shall be paid for at cost less their scrap value, if they prove satisfactory. If the test is not satisfactory the contractors shall receive no recompense.

PAINTING.

187. All surfaces in contact with each other must receive one coat of red oxide-of-iron paint or other metallic paint mixed in pure linseed oil, approved on sample by the Engineer of the railway company.

188. All work before leaving the shops must be thoroughly cleansed from all loose scale and rust, and be given one good coat of pure raw linseed oil, well worked into all joints and open spaces.

189. All surfaces that will be inaccessible after erection must receive one coat of the approved paint during erection, the iron to be perfectly cleaned before painting.

190. The railway company will paint the structure after erection.

191. All planed or turned surfaces must be coated with white lead, mixed with tallow, before shipment.

192. No painting will be allowed during wet or freezing weather.

FALSE WORK.

193. The contractor will furnish all necessary false work and remove the same after the completion of the bridges, leaving the several streams and rivers unobstructed, except the actual space occupied by the masonry.

RISKS.

194. The contractor shall assume all risks from floods and storms, and also casualties of every description, and must furnish all material and labor incidental to or in any way connected with the manufacture, erection and maintenance of the structure until its final acceptance.

195. If any patented parts be used, the contractor shall protect the railway company against any and all claims on account of such patents.

PRESERVATION OF OLD MATERIAL.

196. In the erection of bridges, the contractor will be required to remove all old material in such a manner as will not impair its future use in structures similiar to that from which it was taken, unless otherwise agreed.

MAINTAINING TRACKS.

197. The contractor will be required to maintain the track in proper condition for the passage of all schedule trains without delay, except when previously arranged for by the Division Superintendent.

FINAL TEST.

198. Before the acceptance the Chief Engineer of the company may make a thorough test by passing over each structure the specified trains or their equivalent at a speed not exceeding thirty miles an hour and bringing them to a stop at any point by means of the air or other brakes, or by resting the maximum train load upon the structure for such period of time as he may deem proper.

SPECIFICATIONS FOR SECOND-CLASS BRIDGE SUPERSTRUCTURE.

FOR DIVISIONS AND BRANCHES CARRYING LIGHT TRAFFIC.

1. The loading will be the same as for first-class bridges, and the bridges fully conform to the specifications for first-class bridge superstructures, excepting as follows:

(1) Outside of the lateral system, the stresses due to wind and centrifugal force need not be provided for unless they exceed 40 per cent. of the stresses due to dead and live load.

(2) The unit strains will be modified as follows:

TENSION.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
I-beams (by moments of inertia).....	8,500	8,500	Will not be used.

COMPRESSION.

	WROUGHT IRON.	SOFT STEEL.	MEDIUM STEEL.
Trestle posts.....	$7{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)-30\frac{l}{r}$	10 % greater than iron.	20 % greater than iron.
Intermediate posts.....	$7{,}000\left(1+\frac{\text{min.}}{\text{max.}}\right)-40\frac{l}{r}$	" " " "	" " " "

Stresses not specified will be the same as for first-class bridge superstructures.

(3) One-sixth ($\frac{1}{6}$) of webs of girders will be considered available section in each flange, except at web splices, where the full section shall be provided for by extending the flange plate or by the addition of cover plates.

DISCUSSION.

By C. S. Sims, Jr.

October 17, 1891.

I would suggest the following changes to Mr. Lewis' specifications for first-class bridge superstructure:

Ties.—Ties should be 8″ x 8″ x 10′ white oak (instead of 8″ x 10″, which is very heavy) spaced 14″ between centers and notched $\frac{3}{4}$″ over stringers. I would also advise notching tie for guard-rail $\frac{3}{4}$″, because in case of a derailment it would greatly help to hold guard-rail in position.

Guard-Rails.—Guard-rails should be 8″ x 8″ Georgia yellow pine, in lengths not less than 18′ unless bridge is shorter, and should be notched $\frac{3}{4}$″ over ties, as $\frac{1}{4}$″ notch will soon wear away and let ties slip out of position; also, in case of derailment, a $\frac{3}{4}$″ notch will prevent bunching, while a $\frac{1}{4}$″ notch would not. Guard-rails will be bolted to each end of every third tie (instead of every other tie), and *the same* ties will be bolted to stringers by tie hooks at each end of every third tie. For if ties are bolted to stringers every third tie, and wheel-guards bolted to ties every other tie, one half of your wheel-guard bolts are wasted, because they are bolted to ties which are not bolted to stringers.

Spacing of deck girders and I-beams should not be over 6′ or 7′ center to center.

By Chas. S. Churchill.

October 17, 1891.

I consider the specifications presented by Mr. Lewis as quite good in most respects. They follow those of the Norfolk and Western Railroad Co. very closely. I would object, however, to the wide spacing of stringers and plate girders. We use 6′ 6″ center to center. An addition of 10,000 pounds to each lateral rod stress for initial tension, I think, is unnecessary and misleading and better covered by a minimum section. I do not see why web members of plate girders are specified to be always of steel.

The notching of the guard-rail on the ties, which is specified at only $\frac{1}{4}$ inch, is quite too small; it should be not less than $\frac{3}{4}$ inch.

By E. E. Russell Tratman.

Read October 17, 1891.

In regard to the "general description," I think all modern first-class bridge specifications should include provision for solid floors, for inside iron or wooden guard-rails extended well onto the approaches, and for rerailing guards. Ties should be spaced not more than four inches clear. The outside wooden guard-rails should be notched or boxed out $\frac{3}{4}$ inch or one inch over ties, as $\frac{1}{4}$ inch is not sufficient to prevent bunching in case of a derailment. Blocking between the ties has been suggested to prevent bunching; but I do not think it is often used.

By Henry B. Seaman.

Read October 17, 1891.

In glancing over the specifications, and after listening to the remarks of Mr. Lewis, I have thought that the reason for the exclusion of steel from bridge work was not clearly understood. It is not that we cannot obtain a uniform product, for the production of steel is quite as uniform as that of iron; neither is it because we do not understand the material we receive, for we do understand it, and it is because of this fact that it is not used.

Steel is a refined, ductile, homogeneous cast iron, rather than a fibrous wrought iron; and although the recent practice has been, gradually, to reduce the percentage of carbon until its composition approaches more nearly that of wrought iron, it has never yet been given a fibrous structure, and until this is done the objection to its use will not have been removed.

Tests in a laboratory, under constant strain, are of no value whatever as a criterion for the use of steel in railroad bridges. The objection to its use is, that the slightest flaw—so fine as to be imperceptible under the closest inspection—may, under vibratory strains, lead to the destruction of the member. No inspection can be close enough to avoid this danger, and no amount of reduction of carbon will alter the homogeneous character of its structure, to which this danger is due. The chief care in the maintenance of iron bridges, and the one to which the closest inspection is directed, is the development of flaws in the details. There are members in bridges which are strained 50 per cent.

more than ordinary specifications allow, and which have been used for years and, in the main, are perfectly safe; but there are details which, though thoroughly sound to all outward appearance, have suddenly developed flaws which would have caused the destruction of the bridge, had they not been detected before the passage of a train. So long as the character of steel is such as to favor the development of these flaws, its use is objectionable in this class of work.

I notice in the specifications that the Launhardt formula is used for the allowable strains of truss members, while fixed strains are used for girder spans and for details. If the Launhardt formula, or the principle of the fatigue of metals on which it is based, is applicable to truss members, it is even more applicable to the floor system and to details, and its omission in the latter would consistently require its omission altogether.

The objection to the use of the Launhardt formula is the amount of additional labor its application involves—and this objection is a serious one to those who find it necessary to do a great deal of work in a short space of time. It is also objectionable in that it implies a definite knowledge of the property of fatigue, which we do not possess. The fact remains, however, that its adoption was a marked improvement upon older methods of proportioning, and has long since necessitated serious modifications therein.

In spite of these objections to the Launhardt formula—on account of which it may eventually be abandoned—it will probably remain in use until some equally rational, though less laborious, method is devised. An examination of the experiments on which the formula is based, indicates that it is quite as consistent with their results to consider the destructive effect of active strain as a fixed ratio to the effect of quiescent strain. Under these circumstances the dimensioning would be much simplified by the use of different unit strains for live and for dead loads, with proper provision for impact. To this end Mr. C. C. Schneider has framed the specifications of the Pencoyd Iron Company, wherein the live load is reduced to equivalent dead load by a constant in the formula for impact.

Another matter to which I should refer is the indiscriminate

use of the word "stress" for "strain." The former originated in a refined distinction, which it is unnecessary to carry into practical work. It matters little to what "stress" a piece is subjected, provided it does not receive a corresponding "strain." It is the unit "strain" against which the piece is proportioned.

The question of writing a complete bridge specification has become a very serious one. No specification is considered complete unless it provides for every possible contingency, and the accumulation of experience is producing volumes. This will probably result, in time, in a specification which will be complete in all essentials, but will leave questions of personal preference to the designer or to the approving engineer. The value of carefully designed details is not yet fully appreciated, and until this is the case there will be very little designing by railroad companies.

Empirical specifications are to be deprecated as being unscientific. If the experienced designer can obtain his results without following the routine of calculation outlined, it is his privilege to do so; but to specify that a given ratio of the dead load shall be applied to either chord, or that wind-pressure should be estimated at a fixed pressure per lineal foot, is justified only in the special cases where these conditions are true. In general specifications, particularly as applicable to long spans, the dead weight should be distributed where it is applied, and the wind-pressure should be based upon the area of surface exposed.

In lattice girders a double-web system is preferable to single, as being stiffer and approaching more nearly to the conditions of a plate girder. The calculated strains are only approximate at best in riveted joints, and deflection increases their ambiguity.

Where double I-beams are used they should be placed directly under the rail, as otherwise the load will not be evenly distributed.

The use of cast iron should be discouraged even in bed-plates. In old bridges cast-iron bed-plates are usually found cracked.

I do not approve of the distinction between $\frac{7}{8}$-inch rivets for main members, and $\frac{3}{4}$-inch rivets for laterals. The number of rivets is proportioned to the strain, whatever their size, and this

should be governed by the thickness of metal and size of member, without respect to its location in the bridge.

Skew spans should be avoided wherever they can be built square, and under no circumstances should they be skewed more than 45 degrees. The time has passed when it was necessary to work out skew spans to illustrate the skill in calculation.

The specification in paragraph 177, that "a majority of tests fill the specification," is very lax. Section 17 and also a part of 20 are included in section 14. Section 81 is likewise included in 78.

By James Christie.

Read October 17, 1891.

As I understand Mr. Lewis, he would encourage the use of soft steel by specifying for it the same treatment as for iron; or, if the punch and shears are good enough for wrought iron, they exercise no greater injurious effect on soft steel.

This is still a disputed question, which can only be decided by impartial investigation. The conflicting statements afloat may derive some force from personal bias or prejudice. I can not agree with Mr. Seaman in his condemnation of steel—the extended use and growing confidence in this metal do not harmonize with his statement.

The prejudicial influences that attend certain processes of manufacture are now fairly well known, and can be either avoided or remedied. The distrust of steel, so prevalent a few years ago, has largely disappeared, and a state of tolerance is established. The engineer is usually willing to use steel, but not so willing to pay more for it than for iron.

An evidence of this is the extended use of steel eye-bars for tension members, the iron eye-bar is rarely used now, simply because the steel can be more readily and cheaply made than the iron eye-bar. But so long as engineers are satisfied with the punching and shearing treatment for iron, and demand drilling and planing for steel, there will be a difference in the cost of built-up structures of the two materials, remembering that ten holes can be punched while one is being drilled, in ordinary thicknesses of bridge material. Mr. Lewis distinctly specifies where soft steel or medium steel may be used respectively.

As these grades blend into each other without any real distinction, we have the promise of much confusion, and consequent friction between manufacturers and inspectors. Would it not be better for engineers to specify a certain grade to be used for all purposes? They would be surer to get a uniform quality, and to have their demands more promptly met.

I am told that it is the practice of one of the largest manufacturers of structural steel in Great Britain to make but one grade of steel.

By W. H. Burr.

Read December 5, 1891.

The literature of superstructure specifications indicates, I think, that the minds of engineers are not entirely agreed as to the matter or the manner of the things to be specified. It is a matter of relief, therefore, to observe that Mr. Lewis has not exceeded in volume or in multiplicity of detail a considerable number of specifications already in use. On the contrary, I think he is to be congratulated on having produced a body of printed directions for the guidance of bridge builders comparatively free from the contradictions and obscurities, not to say absurdities, which have characterized too much of this class of writings. Yet it is difficult to see why, in the present state of tolerably well-defined engineering knowledge regarding superstructure, design and nature of material, it should be necessary to complicate matters with twenty-one pages of detailed instructions, when eight or ten, at the most, can be made to cover the same ground in a comprehensive but concise manner, without losing the slightest degree of clearness.

We all agree, of course, that specifications should be clear, concise and comprehensive. It may also be stated with equal emphasis and confidence that instructions covering well-recognized and long-established features of designs and methods of accomplishing results, may and should be compressed into clear and simple general terms, rather than extended into fatiguing and endless detail. Essential points not well understood generally, or affected by local or special considerations, need detailed emphasis and elaboration otherwise entirely inexcusable. It is

unbusiness-like, and exhibits either professional inefficiency or pedantry, or both, to burden and befog the inception of such an everyday piece of work as the building of any one of nine-tenths of the railway bridges of the country with infinitesimal and microscopic instructions about what all engineers and all honorable and well-managed structural concerns are already entirely agreed upon. Especially is this the case when, as in the present instance, all working drawings must be submitted to the chief engineer for approval before any material can be rolled or work done. It certainly is not necessary at this day to state in all detail that heads of rivets must be full, round and conc entric with shaft; that holes must be accurately laid off and punched; that no drifting will be allowed; that countersinking must be neatly done; that field riveting must be reduced to a minimum; that pin-plates must have rivets enough to transfer the pin-pressure which they carry; that attachment of lateral systems must be thoroughly efficient; that portal and intermediate knee-braces shall be used, the former as deep as head-room will allow; that ends of members making contact joints shall be not only milled, but milled to *exact* length and angle (something, by the way, that never has been done and probably never will be), and so on, *ad nauseam.* These things, and their like, are as clearly understood before the specifications are read as after, and probably more so in many cases, while the corresponding shop operations of every first-class bridge company in the country are not at the present time in the slightest degree affected by them. Any shop misunderstanding or negligence on these standard points is cleared or corrected by the inspector or shop superintendent, and is neither avoided nor remedied by the verbosity of the specifications. At least a few of the most prominent and successful engineers of this country have never incorporated such features in their specifications, and their utter uselessness, if not worse, is thereby well established. A few well-framed paragraphs, indicating the general character and quality of the work desired, secure all attainable results in these respects, and leave the special features to receive their due prominence under detailed treatment.

Multiplicity of detail inevitably leads to obscurity and contradiction. Under paragraph 161 (*e*), for instance, it is reasonable

to suppose that rivets are to be of medium steel, yet paragraph 181 tells us that they will be of soft steel. Again, unless the eye-bar item is very small, it is safe to say that all the bars are never all bored at the same temperature, and it is quite superfluous that they should be, with the usual continuous iron bed of the eye-bar boring machine. Nor is it at all probable that they are ever bored within $\frac{1}{64}$ inch of the ordered length, unless by a happy accident. The ordinary methods used in checking the lengths of bored eye-bars involve a probable error of nearly or quite a sixteenth for usual lengths under the most careful manipulation. If bars measure within $\frac{1}{32}$ inch of ordered length, the highest practicable degree of accuracy, with the methods comonly in use, has been reached. Indeed, I have known steel eye-bars between 50 and 60 feet long, apparently differing in length $\frac{5}{32}$ inch, coupled on opposite sides of a compression member from which they also differed in length nearly one-eighth inch by measurement, which gave no sign of the slightest irregularity in length in the completed bridge, although they were minutely examined with that object in view.

I see no advantage or real object to be gained in placing arbitrary limits to the number of rivets at the ends of compression members, or their pitch, or fixing absolutely the limiting angles of web members, collision struts, etc. A single sentence can be made to express the general principles governing such details, and nothing more is needed. The very important detail of the forked ends of compression members receives in paragraph 125 the scantiest treatment. That detail is one of great importance and has heretofore received very inadequate consideration. Enough tests of full-sized members of this sort have, however, been made to permit a fair foundation for a working formula, and well-defined quantitative instructions for the proper design of the detail should be given.

The practice of placing stringers on the top of floor beams (permitted by paragraph 61) has long since been abandoned, in the main, and should never be allowed in any first-class bridge.

The old requirement that legs of trestles must be so inclined as to avoid all tension on the windward side of the viaduct, appears again in paragraph 24. There are many excellent via-

ducts which will not fulfill this condition under an empty train with the usual wind-pressures prescribed, nor is it advisable that they should. With proper anchorage, which may be easily secured, a small amount of wind tension, under the greatest wind load prescribed, is not objectionable, while the excessive batter of posts frequently required to avoid it might be very objectionable.

I can imagine no valid reason for limiting the size of steel bars to 8 inches by 2 inches. Some very excellent 8-inch bars thicker than 2 inches have already been made, as well as some very satisfactory 10-inch bars. It is true that the quality of material in these large bars needs to be carefully guarded; but that is easily done by determining the quality of the steel and securing the proper amount of reduction in the rolls.

That portion of Mr. Lewis' specification which is to be specially commended, covers the use of steel. It may be an open question whether it is advisable to insist on chemical requirements if the physical are secured, but I think he is decidedly right in naming an upper limit to the phosphorus, although 0.10 per cent. seems rather high even for open-hearth material. Again, if a phosphorus limit is to be named at all, I think it most essential that the rivet material should be specifically covered by it. A rivet limit of 0.06 per cent. for Mr. Lewis' "soft steel" will secure rivets capable of sustaining an amount of torture and abuse that is most surprising. I have subjected such rivets to treatment that would have ruined the best iron, with little or no appreciable deterioration.

While I am aware that I shall not be supported in my statements by all users of structural steel, yet I am convinced by my own experience with the grade of metal called by Mr. Lewis "soft steel," that it can be properly treated like iron in all the shop manipulations of punching, shearing and riveting. Punches and dies and shears should be in good order, and gross abuse, to the extent of starting cracks, should be carefully avoided. But I am satisfied that with quite ordinary care, "soft steel" (54,000 to 64,000 pounds of ultimate resistance) will not suffer more than iron, and usually less. It is, of course, a matter of experience to determine just where the planing of sheared edges and the reaming of punched holes should begin; but I should

consider it quite unnecessary for compression members below an ultimate limit of 64,000 pounds per square inch, with other qualities as found in first-class structural steel.

I limit the removal of the reaming restriction to compression members, in spite of the fact that I believe low steel is not more injured by punching than is wrought iron, because any possible injury to the material near the upper border of the privileged field (not yet clearly defined) would be much more serious in tension than in compression members, and for the incidental reason that reaming is a little more in line with the creditable tendency toward improvement in shop processes at the present time.

It would be my preference, therefore, to specify reaming and edge planing for steel tension members; yet, for the reasons mentioned, I do not make this point a criticism against the paper under consideration, and I would make the observations which follow, whether the rivet holes in tension members are reamed or not.

It is necessary to notice, in passing, a little confusion due to Mr. Lewis' classification limits of soft and medium steel overlapping each other. A portion of the two fields (*i. e.*, 60,000 to 64,000) is subject to two different sets of requirements for elastic limit, stretch and reduction.

There is room for a considerable difference of opinion and much discussion in regard to the intensities of working stresses prescribed by Mr. Lewis. Those indicated for wrought iron are mainly in harmony with the best practice of the present day, although 6,000 and 4,800 pounds per square inch for the shearing of shop and field rivets respectively are too low, in view of the fact that the shearing area is that of the rivet before being driven. With the usual inspection, 7,500 and 5,500 are low enough, and there certainly is no good reason for taking a lower value than the former for iron pins. Again, I assume that the minimum over maximum qualification has been so introduced in the straight line column formulæ as to give the requisite relations to known experimental results with full-size columns.

I do not think that either the relative or absolute increase of values over those for wrought iron, for soft and medium steel, are

in every case justified by our experience with those metals. The reliable character and great enduring qualities of Mr. Lewis' "soft steel" entitle it to a greater proportionate part of the total increase for steel than he has allowed. It is more in harmony with my own experience to assign, in general, to soft steel at least two-thirds the increase due to medium steel. I believe that proportionate advantage is justified by its superior capacity for resisting fatigue as well as its greater indifference to the effects of ill-judged shop manipulations. Even with punched holes in soft steel, I think that item *a* for tension members would be more in accordance with experience if 6,000 were taken for that material and 6,500 for medium steel; and similar relations for items *c* and *d*. I cannot imagine any sufficient reason for assigning the same value of 8,000 pounds for the tension flanges of iron and soft steel rolled beams. If 8,000 is used for the former, 9,000 can certainly be taken for the latter.

Taking the results of experiments as a whole, I am also constrained to believe that they indicate at least 15 per cent. increase of resistance for soft steel columns over those of wrought iron, with from 20 to 25 per cent. for medium steel, rather than 10 and 20 per cent. respectively.

The high capacity of soft steel for enduring torture fits it eminently for alternate and combined stresses, and for that reason I would give it 15 per cent. increase over iron, with about 22 per cent. for medium steel.

Shearing tests on steel seem to show that 15 and 22 per cent. increases, for the two grades respectively, are amply justified.

I should not hesitate to assign 15 and 22 per cent. increases over values for iron for bearing and bending of soft and medium steel as being within the safe limits of experience. Provision should also be made for increasing pin-shearing, bending and bearing stresses for increasing ratios of fixed to moving loads.

In closing, I desire to say that my criticisms of specifications lumbered with masses of superfluous paragraphs, minutely prescribing what everybody has long ago accepted, are not specially directed against those of Mr. Lewis. I consider the latter in the main most excellent, although I think revision in some of the details could be advantageously made; but I do wish to speak in

no uncertain terms against the prevailing tendency to cumber specifications with a fatiguing mass of non-essentials, and thus not only render them confusing and difficult to understand, but utterly destructive of that prominence which should be given to essentials and such special features of design as may be required in any particular case.

By Palmer C. Ricketts.

Read December 5, 1891.

The specifications of Mr. Lewis give evidence of much care in their preparation, and bridges built in conformity to them would certainly be first-class structures. The clauses determining the quality of material to be used are particularly good, as are also those which determine the comparative value of the allowed unit stresses for iron and steel.

As to those which relate to the use of steel: Whilst it might not be objectionable to compel the use of steel in all cases for eye-bars and pins, it hardly seems advisable for most railroads to do so for all web plates. In plate-girder spans, for instance, the webs, whether of steel or iron, should not be less than $\frac{3}{8}$ inch thick, and as practice has clearly shown this thickness in iron to be sufficient for ordinary single-track spans, the necessity of introducing a metal which increases the cost of shop-work is not apparent. Of course, for large girders or heavily loaded ones, steel webs should often properly be preferred. Some of the other clauses might, I think, be criticised as follows:

It seems unnecessary, and perhaps inadvisable, to specify that stringer beds must be of cast iron. Although suitable ones can be made of this material, it would be better to replace it by wrought iron under stringers as well as elsewhere in bridges, except in special cases.

For general specifications, I believe the clause which compels stringers in single-track through bridges to be placed 9 feet apart, and the consequent use of ties of greater scantling, to be an unnecessary one. With proper guard timbers no greater safety is secured by a 9 than by a 7-foot spacing.

On many roads using snow-plows, a guard timber 7 inches

high, notched only $\frac{1}{4}$ inch, as called for by the specifications, would be impracticable. These timbers should not project more than $\frac{1}{2}$ inch above the top of the rail, and they should be notched at least 1 inch over the ties, to prevent bunching, or to aid in preventing it.

Although the clause requiring all spans over 100 feet in length to have pin-connected trusses is quite generally found in specifications, it is not by any means certain that through pin-connected trusses of this length, 20 feet high, with four or five panels, make safer, stiffer or better bridges than well-constructed lattice bridges of the same span; and I believe the limit should be raised to about 120 feet.

Notwithstanding that the surface presented to the wind, per lineal foot, is generally greater for spans over than for those under 200 feet in length, I do not think it necessary to very much increase the wind-pressure per lineal foot for the larger spans, because the few experiments made and the empirical data collected show that the greatest wind-pressures are generally distributed over very limited surfaces, and it is very doubtful whether a pressure approximating 450 pounds per lineal foot has ever been exerted over the whole length of any span of considerable length in this country. It is rational, I think, in providing for wind-pressure, to distinguish between loaded and unloaded bridges.

It is not believed that provision should be made for cross-ties resting directly on the bottom chords of bridges, nor that this method of construction should be recognized or allowed.

In view of the comparatively small number of experiments showing the actual strength of full-sized chord compression members as generally built, an allowance for the effect of their weight in the use of the long-column formulæ seems a needless refinement.

Although the clause requiring the minimum thickness of the connecting angles between stringers and floor beams to be $\frac{1}{2}$ inch is a good one, it is hardly advisable to compel the use of equal-legged angles, as unequal-legged ones are often sufficient to give the required bearing and shear.

It is believed that the clause relating to stiffeners would often compel the use of an excessive amount of material.

Where heavy pieces are to be shipped in sections, there would be found, I think, practical difficulties in the way of making splices break joints with each other, so that one piece only should be spliced at any point.

The advisability of compelling the use of vertical web members in all lattice bridges is not apparent. It would be inferred from the specifications that the bars in double as well as in single latticing must make angles of 60 degrees with the axis of the piece. This would be quite unnecessary. In the better class of bridges compression members are almost as likely to have metal wasted in latticing as to have too little of it used, as experiments on the failure of full-sized columns show.

By Alfred E. Hunt.

Read December 5, 1891.

I fully agree with the general position taken by Mr. Lewis in the matter of a specification and, in his paper regarding it, as to the advantage of the use of soft steel in bridges; but would suggest a modification of his specification regarding the use of medium steel to the requirement of 60,000 to 68,000 pounds tensile strength per square inch, instead of 70,000 pounds; and would strongly advise a requirement as to the character of the fracture of tensile tests being entirely silky in sections of less than 7 square inches, and in larger sections the test specimen not to contain over 25 per cent. crystalline or granular fracture. I would further advise a similar requirement for the character of fracture of test specimens from soft steel, with the provision that it should in all cases be silky in fracture. According to the specification which Mr. Lewis suggests, a test specimen cut from a steel eye-bar, or from a pin, giving 69,900 pounds tensile strength per square inch, with 20 per cent. elongation and 40 per cent. reduction of area, with fully 50 per cent. of fiery crystals, would not be rejected by the specifications; although undoubtedly Mr. Lewis would want such material rejected.

I would strongly advise also the drifting test as a requirement of both soft and medium steel; the requirement being worded about as follows: "Steel to be capable of having a hole, punched

for a $\frac{3}{4}''$ rivet, enlarged by blows of a sledge upon a drift-pin until the hole (which in the first case should be punched $1\frac{1}{2}''$ from the roll-finish or machined edge) is $1\frac{1}{2}''$ diameter in the case of soft steel, and $1\frac{1}{4}''$ diameter in the case of medium steel, without fracture." This drifting test is an excellent requirement not only as a matter of record, but as a measure of the ductility of the steel.

I would further suggest that in Articles 170 and 173 the words "widely varying" should be inserted, so as to read: Article 170: "Each widely varying section and each rolling will be tested." Article 173, last sentence: "Each melt of steel will be tested and each widely varying section rolled."

In the requirements of the tests for wrought iron, Article 164, the formula (which is modeled after the one recommended by the Standard Bridge Builders' Specifications) is used for the ultimate strength for bar iron in tension rather than actual figures given This it seems to me is unfortunate, as this formula has to be understood by the subordinate officers of the manufacturing concerns, who often are not conversant with working out formulæ of this kind, and might therefore misunderstand and misinterpret the meaning. Again, it requires some little calculation on the part of the inspectors with each result. I should much prefer to see the same requirement, 48,000 or 49,000 pounds tensile strength, inserted in place of this formula.

Further, I believe the requirement of 18 per cent. elongation in 8 inches for bar iron to be too severe. I should have no hesitation in accepting ordinary bar iron in tension which stood 48,000 pounds tensile strength with 16 per cent. elongation, provided the *character of fracture* were fibrous. I believe that this requirement regarding the character of the fracture should be inserted in the specifications here as well as for steel; and that the conditions regarding this should be carefully considered in accepting or rejecting bar iron.

I would call attention to the fact that sheet aluminum is now being used quite satisfactorily, and undoubtedly will be used very extensively, to replace sheet lead as a bearing material interposed between the pier boxes or bed-plates and masonry; the aluminum having the advantage of the lead in that it will

take a square bearing and does not have the disadvantage of flowing as much as lead; and has the further advantage that it will not oxidize or corrode in the work; and at present aluminum is furnished very close to the price of lead, when the difference in weight is taken into consideration.

I do not agree with Mr. Lewis' rejection of medium steel for solid rolled beams; but, on the contrary, would allow a unit strain of 9,000 pounds per square inch (by moments of inertia) on such steel; allowing either soft steel or medium steel. As a matter of fact, the bulk of the steel for beams runs from 58,000 to 64,000 pounds tensile strength, and, I think, can safely be used with a unit strain of 9,000 pounds.

Regarding the inferior quality of the wrought iron furnished by the mills for bridge purposes to-day, my own experience agrees in a general way with that Mr. Lewis has stated—that is, that wrought iron furnished by many mills where they are also manufacturing steel for structual purposes is not up in quality to what it used to be, attention not being given to the iron; and, further, an idea is prevalent at many mills that iron is only used because the purpose for which it is designed is not an important one and that "most anything will do" in iron; in fact, the manufacturers interpreting the requirement in some specifications that "*either* iron or steel can be used" to mean "*both* iron and steel" can be used together in filling the same order. Some of the mills are not using top-cover plates in their iron piles, as they used to do; and are in every way cheapening the cost of manufacture of their iron. There are, of course, many exceptions to this state of things. Some of the old standard manufacturing concerns are furnishing fully as good quality of iron to-day as ever before; but the remark has application, nevertheless, to a considerable number of mills. In the Pittsburgh district this trouble, within the last year, has been intensified by the irregular supply of natural gas with which the puddling furnaces have been furnished, causing, in many cases, very poor work—trouble which has been more severely felt in the product of the puddling than of the steel furnaces.

By F. H. Lewis.

Read January 2, 1892.

I have been much interested in the discussion of the specifications, and am indebted to the gentlemen who have participated in it, for very courteous treatment, and for a number of good suggestions which I shall be glad to adopt in revision.

With the exception of one or two points, however, it is not my intention to review the matter at length now.

The first of these points is Professor Burr's objection to detailed specifications. It is desirable to say something in reply to this, because I have purposely added a considerable mass of detail to the specifications, and my reason for doing it is precisely the one which Professor Burr urges against such a course. That is, I put it there because, with the better class of bridge builders, it is largely unnecessary. It is there for the protection of such companies as much as for any other purpose.

It should be remembered that requirements calling for first-class work and close supervision are generally no hardship to such concerns. On the contrary, these conditions are distinctly advantageous to them, since they are not forced to meet the competition of builders who are not prepared to fulfill these conditions.

Bridge work is now figured on very small margins, and, with a certain class of contractors, first-class work will not be furnished unless it is distinctly provided for. Hence, if specifications are silent on these matters, it becomes necessary, both for the engineer and for his inspector, to shoulder the burden of proof and carry points by force of argument (or, indeed, secure them at an additional cost), which would be conceded in advance by the better class of bridge builders. There is no reason why an engineer should voluntarily put himself in such a position. Like many regulations, both social and legal, specifications must contain features which are not intended to apply to the best people.

Again, there is another reason for full details in the fact that bridges are planned now not so much for the loads as for the traffic. They must be working machines, to stand the wear and tear of rolling loads amounting to millions of tons per annum. Nothing, in my judgment, adds so much to the life

of a bridge under these conditions as first-class details; but as we have arrived at no general understanding in regard to reckoning these things, there is evidently room for much greater differences of opinion than there can be in providing for simple strains.

It is for these reasons that the present specifications, and, as Professor Burr truly says, many others, go so much into detail; and this feature will undoubtedly continue, excepting in the specifications of engineers designing their own bridges.

I confess some disappointment that the use of steel has not been more fully discussed. Aside from Professor Burr's well-considered comment, which, I am pleased to find, is almost entirely favorable, there has been little said which is pertinent to the subject. To discuss "steel" in general or abstract terms is merely a waste of time, albeit there is some very good precedent for such a course. Steel is essentially an alloy, exactly as the bronzes are, and its properties vary through a wide range, from material having a texture much like wax to one which has the properties of glass. Hence, to consider it in general terms as a simple concept is nonsense.

The very able papers which Mr. Wm. Metcalf has read before the American Society and the Pittsburgh Club are open to criticism for lack of discrimination in this respect. The properties which he ascribes to "steel," while they no doubt hold true of the harder steels, are but very remotely, if at all, true of our structural steel. For a really joyless task let me commend to you a series of experiments to produce Mr. Metcalf's phenomena in our soft structural steel. I speak from experience.

The most important suggestion which I have had on the steel question was received outside the discussion of the Club, and was this: That it was desirable to place a limit on the thickness of punched steel. You may remember that in my original paper I said that it was desirable to use moderate sections in members subject to impact, since the thicker the material the greater the damage in punching. But the failure to give this suggestion practical effect in the specifications is, I think, the most conspicuous omission to which my attention has been called.

The tests which have been presented show that the steel held

its value, after punching, better than iron, up to say $\frac{3}{4}''$ thickness, when the percentages in steel and in iron were just about equal. But these tests also show that the value of the steel decreased quite rapidly as the thickness increased; the percentages running down from about 100 at $\frac{3}{8}''$ thickness to 75 at $\frac{3}{4}''$ thickness.

In iron the percentages seemed to be much more constant, the range being only from 82 to 72 per cent. (See Tables III and IV.) In order to make this fact more clearly apparent, I have had the results platted as a diagram, which shows the percentage values of the punched iron, the punched steel with open holes, and the punched steel with riveted holes, for different thicknesses of metal. It also shows a mean line for steel. (See Plate A.)

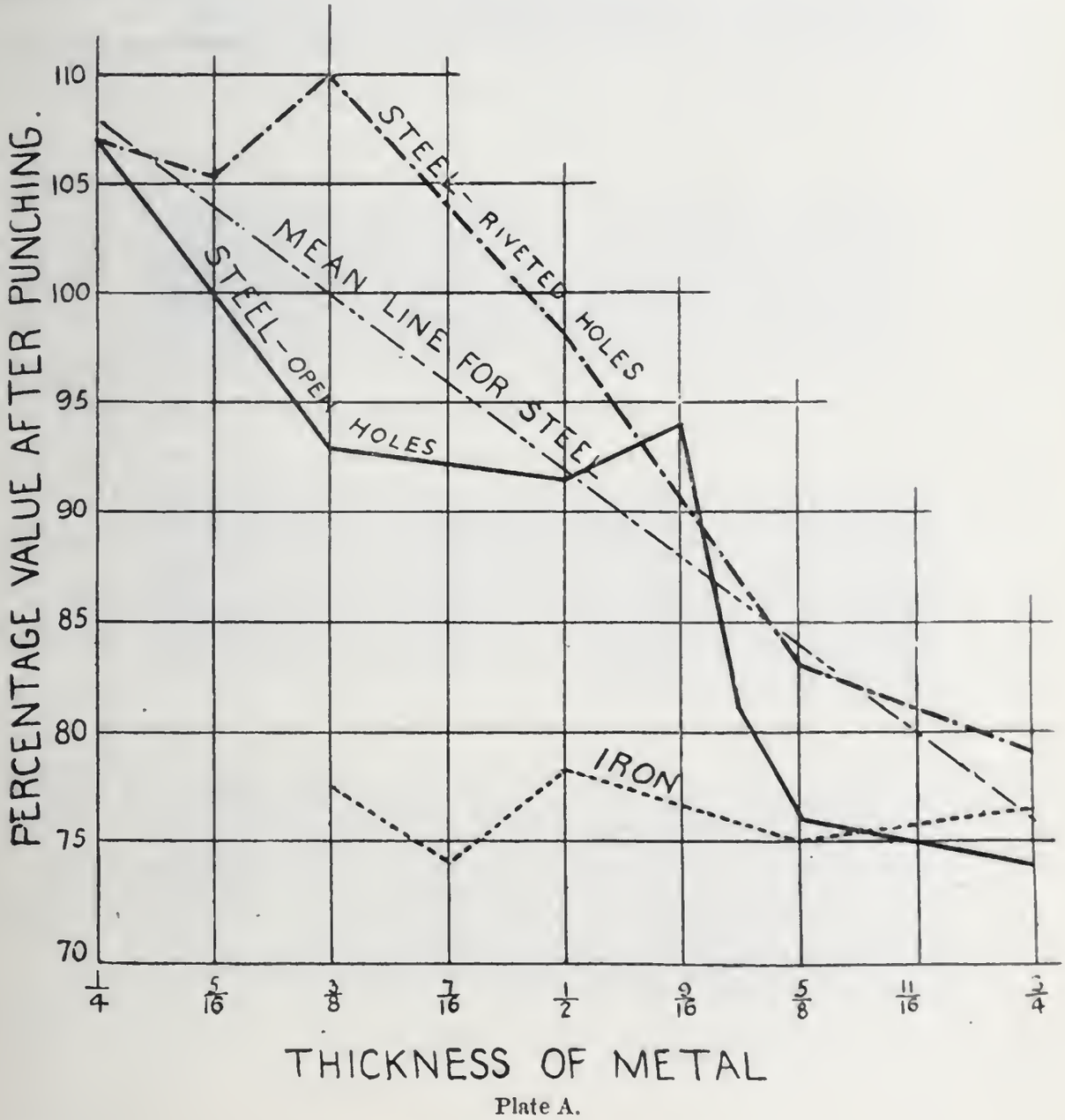


Plate A.

In addition to this decline in percentage value, there was a gradual change in the character of the fracture from fine silky in $\frac{3}{8}''$ material to 100 per cent. granular in the $\frac{3}{4}''$ material. This gradual change formed such an interesting feature that I have had specimens photographed, and ask you to note how the granular structure first appears at the edges of the holes and radiates from them in larger percentages as the thickness increases. (See Plate B.) In order to show the latter characteristics more fully I have prepared Table VII, which gives the details for most of the tests of soft and medium steel which appear in Tables III and IV. The tests of iron did not of course show granular fractures, since the normal structure of iron is not granular as that of steel is. But it was apparently very dead, and I am not prepared to say which of the two metals was more reliable at $\frac{3}{4}''$ thickness. I am disposed to think, however, that this decrease in value and increase in granular fracture in thick steel should be considered, regardless of a satisfactory comparison in ultimate strength with wrought iron of the same gages.

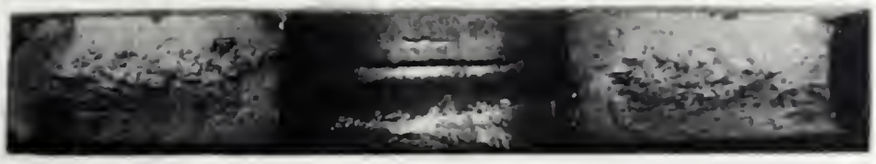
I have decided therefore to limit the thickness of punched material in the specifications, and do this for most members by drawing the line at the gage in which the crystalline fracture becomes evident and the stretching qualities decline. From Table VII it is apparent that all the tests are satisfactory until we pass $\frac{9}{16}''$ thickness. Above that gage there is but one test which would pass muster on the basis I have proposed. I purpose therefore to add a third condition to the use of soft steel, limiting to $\frac{1}{2}$ inch the thickness of material subjected to punching, excepting that in girders over 50 feet long it may be $\frac{9}{16}''$, in top chords and end posts it may be $\frac{5}{8}''$, and in shoes, pedestals and bed-plates it may be $\frac{3}{4}''$.

So far as I know, the only other bridge specifications which take this matter into consideration are the Wheeling Bridge Specifications of Mr. Abbott, which provide a limit of $\frac{3}{4}''$ with a preference for $\frac{5}{8}''$. I am credibly informed that this limit is based on some experiments made by the Dominion Bridge Company of Canada, which, however, have not been published.

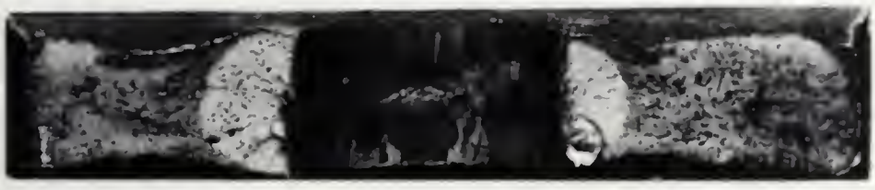
It has rather surprised me not to hear some comment on reaming, from a practical standpoint. The value of efficient ream-



⅜ inch, riveted holes, all silky.



½ inch, riveted holes, all silky.



½ inch, open holes, 20% granular.



$\frac{9}{16}$ inch, open holes, all silky.



$\frac{11}{16}$ inch, open holes, 70% granular.



¾ inch, open holes, all granular.

F. GUTEKUNST, PRINT.

TENSILE TESTS OF STRUCTURAL STEEL AFTER PUNCHING.

ing is unquestionable. All the tests submitted with this paper are evidence to this effect, and I have recognized the fact in the specifications, by putting a sufficient premium on reamed steel for tension members to make it generally advantageous to use it. But in practical work the efficiency of reaming, being based on punching, must clearly share the deficiencies of punching. With good punching the reaming, no doubt, accomplishes its object in members of moderate length and section, but it is quite certain to decrease in effectiveness in long or heavy work, or with bad punching.

Tests of this matter on a large scale are desirable because, if reaming does not accomplish its object in practical work, then we are limited to one of two things in using steel—viz., either to punch it merely, or to drill it in the solid. In such an event I should say punch all material up to half-inch in thickness, and drill all heavier material.

At this time there is but one shop in the United States fitted to do solid drilling on a large scale.

It will be noted that in the specifications as they appear in the Proceedings, the lattice girder, which was a feature of the original draft, has been discarded and a special plate girder substituted, which, it is believed, will meet the conditions better.

VI.

SOME COMPARISONS AS TO THE RELATIVE VALUE OF SOLID, LIQUID AND GASEOUS FUEL.

By Max Livingston, Active Member of the Club.

Read November 7, 1891.

An eminent engineer, who can justly claim that if the best-known names in the profession were mentioned, his would not be forgotten, but whose opinion on political economy will never be authoritatively quoted, stated during a discussion of that topic, that our much-vaunted prosperity and immense accumulation of wealth produced by our industrial development were due solely to nature's good husbandry in past ages, through which we are now enabled to consume with flagrant prodigality the abundant stores of fuel, so carefully hoarded, whose value and utility could not have been conceived by preceding generations. As soon as this bountiful supply of coal, petroleum and natural gas became exhausted, our mode of production would be surperseded by its predecessor—the primitive method in vogue at the time of James Watt's tea-kettle experiments.

Although we need neither apprehend the early exhaustion of these valuable stores, nor agree with our friend's conclusions, there can be no question as to the vital importance to the mechanical world of a cheap and desirable fuel.

The subject has had the attention of the brightest minds in the industrial arts, but so far no revolutionizing changes and improvements have been generally introduced.

It is not the purpose of this paper to describe any of the devices claiming to accomplish the desired object; I only intend to present some comparative figures, derived from careful tests undertaken to ascertain the relative value of coal, petroleum and gas, as they have come under my personal observation.

These tests, made under the same condition with a so-called double-deck tubular boiler, 60″ diameter, 15′ long, connected to an upper steam drum, 50″ diameter, 16′ long, by three necks, 15″ diameter, 12″ high, gave the following results:

1 lb. anthracite coal evap. 9.70 lbs. water from and at 212° temp.
1 " bituminous " " 10.14 " " " " " " " "
1 " fuel oil, 36 Grav. " 16.48 " " " " " " " "
1 cu. ft. gas, 20 C. P. " 1.28 " " " " " " " "

The gas used was that obtained in the distillation of petroleum, having about the same fuel value as natural or coal gas of equal candle-power.

Taking our efficiency of bituminous coal as a basis, which is not greatly at variance with the results generally claimed for it, we find the calorific energy of petroleum to be more than 60 per cent. greater than that of coal; whereas, theoretically speaking, petroleum exceeds coal only about 45 per cent.—the one containing 14,500 heat-units, and the other 21,000. From this we are justified in deducing that the percentage of loss in heat-units in ordinary working is considerably smaller in oil than coal. This result was not obtained under particularly favorable conditions. The furnace had previously been used for coal, and suffered but few alterations, which consisted mainly in the covering of grate bars and placing a barrier of broken fire-bricks, slag, etc., against the bridge-wall, as exhibited herewith.

The oil was sprayed into the furnace, mingled with steam and air at the pleasure of the engineer, by a Mitchell burner, the construction of which is shown on the accompanying figure, and does not differ essentially from that of other oil burners depending on steam and air for efficient work. Besides its higher calorific energy, which alone recommends it as a highly desirable substitute for coal on ocean steamers, petroleum has many other advantages, of which we will enumerate only the following:

Reduction of labor; in many establishments one engineer will do the work that, when using coal, would require him to have several assistants.

Uniformity of steam-pressure, which is much more easily maintained with oil than with coal.

Less cleaning of flues or tubes, and fewer repairs to boilers.

Disappearance of dirt and coal-dust, bringing in its train more comfort and better health to the firemen.

Whether these advantages are sufficient to make petroleum a successful competitor of coal depends on the relative prices of

the two fuels, and as these are mainly governed by transportation tariffs, the comparative cost resolves itself simply into a question of arithmetic for different localities.

The Russians, owing to their exceedingly cheap oil, were the pioneers in solving the problem of its successful use on railroads and steamboats; but that they are not the only ones ready to take advantage of circumstances is proved by the following extract from London *Engineering:*

"Since the month of March, 1890, careful experiments have taken place on the Oroya line to test the comparative efficacy of oil and coal in locomotives. On April 30, 1890, the first regular passenger train in South America, pulled by an oil-burning locomotive, was hauled up to Verrugas, 5,800 feet above the sea level, arriving on schedule time. From this time until September, when the fuel was definitely approved of, an engine ran regularly on the mountain service without a breakdown. Against her was run a sister locomotive burning coal, running for five months alternately, pulling equal trains over exactly the same ground; and it is believed that these trials furnished the best competitive tests of practical oil and coal burning on a railroad.

"Engine No. 1 ran with coal, engine No. 15 with fuel oil. Both engines were exactly alike in other respects. These engines are of the Mogul type, hauling regular trains of five cars, the average weight of each car being 18 tons gross. The total weight of the train, including the tender, was 118 tons. Eight and ten cars were sometimes taken as far as Chosica, from where three and four per cent. grades begin. The present terminus of the Oroya Road is Chicla, 12,218 feet above the sea, and distant from Callao 86 miles. From Chicla to the summit tunnel is about 20 miles. The summit tunnel is situated at 15,720 feet, and it is said to be the highest railway mountain pass in the world.

"The steam-gauge on Engine No. 15 always recorded from 135 to 140 pounds, never falling below 135 pounds. As a rule, the hand stood immovable at exactly 140 pounds, and although the safety-valve would blow off at 142 pounds, so admirably was the fire at all times under control, that it very rarely blew off. On all the grades up to 3 per cent. no smoke showed from the stack.

On the 4 per cent. grades a slight hazy smoke would show at times.

"The average consumption of coal for the month was 79.30 pounds per train mile. The average consumption of fuel oil per train mile was 38.55 pounds, or slightly less than 50 per cent. of the amount of coal used. In the tunnels, the oil proves a great boon to passengers, doing away with the former choking smoke, whilst at all times windows may be kept wide open, with no danger of sparks or red-hot pieces of coal flying in.

"No alterations are made to the fire-box for the use of this oil as fuel, and but a few additions are put to the regular ash-pan. The back damper is completely closed, and a large front damper, with about two square feet superficial opening, is arranged in front. A plate is placed on top of the ash-pan, extending from the front of the fire-box to about the center of the pan. Air is admitted into the furnace through an opening 20 x 14 inches, cut through the plate near the center of the pan. This plate supports the fire-brick at the front of the fire-box, which receives the vaporized oil. These fire-bricks are built up to a height of about two feet, and the whole is surmounted by a brick arch extending to within 18 inches of the back end of furnace. On the sides of the furnace the brickwork extends 2 inches above the mud ring. Only 150 bricks are used for the whole brickwork, including the arch. This brickwork will last from six to eight months.

"The burner is attached to the bottom of the fire-box at the back end. The construction of the burner is extremely simple; it is a cast-iron rectangular box divided lengthways into two compartments, one above the other. The upper one is the oil passage; the lower one, the steam passage; both these passages are 3 inches wide by $\frac{3}{4}$ inch deep. The oil passage is tapped at the rear end for a $1\frac{1}{4}$-inch oil pipe, and the steam passage is tapped for a $\frac{1}{2}$-inch steam pipe. The aperture for the oil passage is 3 inches by $\frac{3}{4}$ inch; the steam aperture is $3\frac{1}{4}$ inches by $\frac{1}{40}$ inch. The oil coming through its passage falls directly on the steam shooting through the narrow slit at the end, and is completely vaporized. With this burner, the bricks do not serve in any way for breaking up the oil, but merely as a white hot retort, in which

air and vaporized oil are mixed in the proper proportions. The supply of air is regulated by the front damper, the supply of oil by a gate-valve worked by a wheel under the fireman's hand in the cab. The steam is never touched excepting when the engine is laying up for any length of time at the station. The fuel and air are under complete control of the fireman, whereby a perfect combustion with no smoke is obtained. The burner is in one piece without any movable parts, and cannot get out of order.

"Steam from another locomotive is used in getting up steam; 100 pounds from cold water has been shown on the steam-gauge in twenty-five minutes, but an hour is generally taken, so as not to strain the boiler. Wood can be used for getting up steam, if necessary. No. 15, after running six months, showed no signs of leaking in the fire-box, nor any other signs of straining. The results of these practical tests are considered very satisfactory, and, as a consequence, everybody in Peru at present is said to be convinced that petroleum is the ideal fuel—the fuel of the future."

A few weeks ago a cablegram from Rome announced that recent experiments with petroleum as fuel for warships had given great satisfaction to naval engineers, and would probably result in the adoption of oil as the sole fuel for the Italian navy.

The superiority of petroleum over coal as fuel for ships has also been demonstrated and recognized in England, where, in enumerating the advantages, particular stress has been laid on the following points:

Saving of space; coal for a given duty occupies double the room required for petroleum.

Facility of maintaining a constant supply of steam at steady pressure with but little supervision, independent of a large crew of firemen and laborers, and the state of the weather.

Gain in speed. "In the case of the London and Pacific Company's steamship 'Ewo,' it is said that while she made $8\frac{1}{2}$ knots with the use of seven tons of coal per day, she reached 9 knots on less than four tons of fuel oil."

But we need not go so far from home to find coal superseded by petroleum as an agent for generating steam. In Chicago and Cleveland a number of important establishments are now con-

suming large quantities of oil under their boilers, and, encouraged by the good results at these points, and eager to abate its returning smoke nuisance, even Pittsburgh, the stronghold of cheap and excellent coal, has awakened to the necessity of grappling with the subject, evidently, judging from current reports, with admirable success, as indicated by the following extract from an article in the *Pittsburgh Dispatch.*

"If there is any lingering doubt in the minds of Pittsburghers as to the applicability and economical use of crude petroleum as a steam-raising fuel, such must be dispelled by the results attained at the Ben Venue power-house of the Duquesne Traction Co. Two things have been demonstrated: that the oil is as cheap a fuel as coal, and that it is smokeless as well as comparatively odorless. The setting of a furnace for oil fuel is not more expensive than the construction of any new furnace, and in the case of old furnaces the change is inconsiderable in cost. In short, it has been successfully demonstrated that crude petroleum can be substituted for both natural gas and coal with economical results. . . .

"The Duquesne Traction Co. has two batteries of five boilers each in its power-house, one running with coal and the other with crude petroleum. Chief Engineer Julian E. Smith, who is responsible for the methods adopted, finds the plan so successful that he has applied for letters-patent for construction of boiler furnaces as adapted to this use.

"Mr. Smith's system is as follows:

"The furnace is divided into three chambers, separated by brick walls extending nearly the entire length of the boiler, which is eighteen feet long. Under each chamber is an air flue, the air passing upward into the combustion chamber through perforations in the floor.

"Crude petroleum is carried from a tank in the yard, by gravity, through pipes to the rear end of the furnace, and introduced through a quarter-inch pipe into the two side chambers, one pipe to each. A steam pipe laid from the front of the boilers passes through the center chamber and is connected by a half-inch pipe with the oil pipe. The two pipes meet in a Reed's burner, the steam driving the oil into the side chambers. The

steam by being passed through the center chambers is completely dried, so that when it meets the oil it forms a gas calculated to give good results in heat. The gas carried through the side chambers meets at the front end, and, sweeping around the bending walls, passes up the center chamber and so into the tubes. The effect of this distribution of the gas is that fully two-thirds of the surface of the boiler is subjected to the action of the flame, which is uniform and spread over the heating area.

"The boilers are kept going day and night at a pressure of 100 pounds to the square inch. One battery of five boilers consumes 30 tons of coal every 24 hours. This, at $1.45 per ton, would be $43.59 per day. The battery of five boilers with the petroleum furnaces consumes 80 barrels of oil in 24 hours, at a cost of 59 cents per barrel, or $47.20 per day. The costs of the respective fuels are thus nearly equal, but the balance is on the side of the oil if the saving in labor incidental to firing with coal is reckoned."

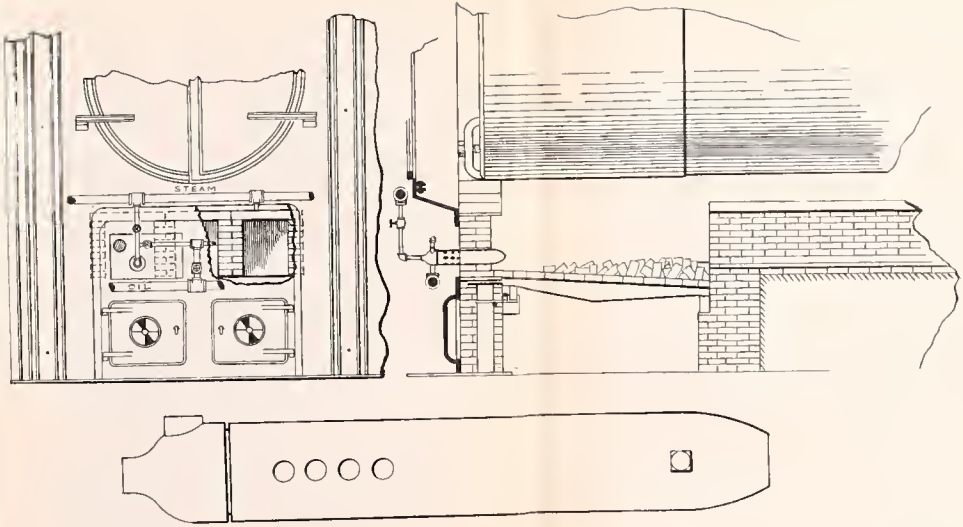
Compared with these enthusiastic reports, the figures which I have presented of the available calorific energy of petroleum appear very conservative.

Let us now consider fuel in gaseous form, in which state it is acknowledged as the ideal heat generator. Although I have heard a sanguine gas and oil operator ridicule the fear of the early exhaustion of these products by the remark that "the Creator did not do business on a retail basis," Pittsburgh and other localities favored by natural gas have learned to their sorrow that reckless waste will not go unpunished, for in their case natural gas for manufacturing purposes seems to be a thing of the past.

As a desirable successor artificial gas suggests itself, which, thanks to recent improvements in the processes of gas making, can be manufactured at a trifling cost.

Having ascertained that 1 cubic foot of gas is capable of evaporating 1.28 pounds of water, and as 1 pound of oil can be converted into upwards of $16\frac{1}{2}$ cubic feet of 20 candle-power gas, we find that by this means nearly the entire theoretical calorific energy contained in petroleum can be utilized in practice.

Experts will confirm that this estimate of the gas-producing



Length 2 Ft.

MITCHELL OIL BURNER.

power of petroleum is not exaggerated. To the contrary, were we to base the production of gas on claims made by people, by no means visionary, we would show an available calorific energy far in excess of that proved to exist in oil.

Converting coal into gas is more complicated and involves greater expense; yet it is claimed to be more economical to make and consume fuel gas than to burn the coal direct, even under boilers, where, with ordinary methods of firing, upwards of sixty per cent. of the energy contained in coal is made available, whereas for metallurgical and other purposes the waste of this energy is appalling to contemplate. Not being in possession of any reliable data as to the cost of making gas from coal, I leave this out of consideration and summarize as follows:

For generating steam, one ton of oil converted into gas is equivalent to 2.08 tons of bituminous coal, and, used in its liquid state, to 1.625 tons of coal.

Pertinent to the subject, though of no practical value as yet, it may not be out of place to bestow a passing notice on the attempt to solidify petroleum, capable of being easily rendered plastic, we are told, and readily molded into any desirable shape.

If the expectations of the inventor should be realized, the introduction of his process would not only revolutionize the oil business, but could not fail to have a far-reaching influence on other industries. He states that "petroleum can be solidified as it comes from the wells, formed into bricks as hard as may be required, and shipped like coal.

"For transport purposes this would occupy about one-fourth the space of coal"—a point of vast importance to steamships, where bunker room is a question of serious consideration. "After being solidified it can be reliquefied by a simple process at a small cost, or may be burned in its solid form, which, when ignited, will not reliquefy, but burn to ash like a cigar.

"The danger of explosion is entirely obviated, so that petroleum may be solidified for warehousing purposes."

But even without this solidification, important though it be in many respects, the claim to superiority as a generator of heat has, as we have shown, to be awarded to petroleum, which, however, does not imply the dethronement of "King Coal," for whom we

may safely predict a long and undisputed reign; for, large as the production of petroleum is for present demands, it is insignificant compared to the output of coal, the latter exceeding that of oil fortyfold in weight.

But this immense production does not justify such enormous waste, the avoidance of which, from the standpoint of the political economist, is of the utmost importance; and no efforts should be spared to eventually obtain approximately the same relative efficiency from coal as is now secured from petroleum.

DISCUSSION.

By James Christie.

What can Mr. Livingston tell us about the use of oil when injected with air instead of with steam? Some years ago we experimented with boilers of 150 horse-power, using steam for the spraying of the oil. Under these circumstances the best results we could obtain were $14\frac{5}{10}$ pounds of water evaporated for one pound of oil. We concluded from these experiments that the use of oil cost about 20 per cent. more than that of coal, and that, with oil at 2 cents per gallon and coal at $2 per ton, the two would be equal as to economy. We have since used oil sprayed with compressed air to better advantage than with the use of steam.

By Carl Hering.

Some years ago I noticed the employment of a burner in which the oil was used without either steam or compressed air. A steel pipe heated to redness was rolled flat, leaving only a capillary aperture between its sides. The tube, so flattened, was then coiled spirally, and heated oil was pumped in, using a small hand pump. It passed out from the end of the pipe under great pressure and formed a flame 20 feet long. One advantage of this burner was that it was not necessary to have an auxiliary boiler to furnish steam. At the start, such a coil can be heated from a stove or from a similar coil. There is no danger of explosion. I have pumped water through a red-hot coil of this kind, and the issuing steam was hot enough to light a match, but no explosion followed.

By Henry G. Morris.

In making Mitis castings, the oil-burner used is composed of a series of V-shaped troughs arranged one above the other, the oil overflowing from the upper one into the lower ones, and the air passing through the burner from one side to the other. It gives a heat sufficient to melt wrought iron in open crucibles in half an hour. With crude oil it is entirely successful for the purpose to which it is applied.

By T. Carpenter Smith.

I would ask Mr. Livingston what trouble he has experienced, in using liquid fuel, from the excessive heat developed. Some time ago we had occasion to use natural gas under some water-tube boilers. As the gas was furnished under contract, and as it was desirable to get all the heat obtainable, we used all the gas we could get. An analysis of the gas in the uptake showed that we were wasting half of the gas consumed, and were taking in eight times as much air as we should. The furnace was remodeled, with the result that we consumed all the gas and only from five to six per cent. more air than we should. The boilers were forced and the fire drove the water out of the lower tubes, so that we came near having a bad accident. It seemed impossible to prevent the firemen from crowding the boilers to make steam. The circulation, no doubt, depends upon the construction of the boiler. In our case the trouble arose from local overheating, which might have been avoided with a boiler differently constructed.

By Mr. Livingston.

In reply to Mr. Christie: Compressed air has been used with favorable results. The general trouble in its use seems to be to maintain the pressure uniform. If this can be done, oil will be found to give better results than coal.

In reply to Mr. Hering: Many experiments have been made with a view to using the oil without either steam or gas, but all have resulted in failure. I have used the burner referred to by Mr. Hering, but it did not do the work. We have tried it thoroughly, but we were obliged to give it up.

In reply to Mr. Smith: We find it a great advantage, under boilers, to use a perforated brick arch. It not only protects the boiler from the excessive action of the flames, but acts also as a regenerator or reservoir for the heat. There is then no overheating. Our boilers, with oil, require fewer repairs than with coal, and the circulation is perfect. The trouble of which Mr. Smith complains may be to a certain extent due to faulty setting. The fire-brick arch makes a perfect combustion chamber, and avoids all smoke, whether gas, benzine or oil is used. There is no trouble with smoke after the first half-hour.

ABSTRACT OF MINUTES OF MEETINGS.

Of the Club.

From October to December, 1891, *inclusive.*

Regular Meeting, October 3, 1891.—President Wilfred Lewis in the chair; present, 39 members and 3 visitors.

Mr. H. W. Spangler apologized, on behalf of the Committees concerned, for the unavoidable delay in issuing the notices for this meeting, and the Secretary expressed his thanks for this acknowledgment.

Mr. John C. Trautwine, Jr., read a paper, compiled from data furnished by Capt. S. C. McCorkle, upon Land-locked Navigation from New York City to Charleston, South Carolina. The paper concluded with a proposed series of resolutions memorializing Congress in behalf of this project. The Secretary read a written discussion of this paper received from Mr. J. Foster Crowell of New York, and submitting a preamble and resolutions as a substitute for those offered by Capt. McCorkle.

The paper was discussed by Capt. McCorkle and Messrs. Rudolph Hering and T. Carpenter Smith.

The subject for the evening, Power Transmission, was then taken up. Mr. T. Carpenter Smith read, for Mr. Saunders Morris, a paper on Electrical Transmission of Power.

The Secretary read, for Mr. Coleman Sellers, a letter communicating information recently received from Switzerland, respecting the Electrical Transmission of Power from Lauffen to Frankfort.

Mr. Carl Hering discussed these papers from the standpoint of a recent visit to the locality referred to.

Mr. B. H. Coffey submitted a paper embodying a theoretical discussion of the effect of centrifugal force on the transmitting power of driving-ropes.

The Publication Committee announced that Volume VIII, No. 3, of the Proceedings, dated July, 1891, had been mailed to the members within the last few days, and

that Volume VIII, No. 4, to be dated October, was being pushed forward with all possible dispatch.

Business Meeting, October 17, 1891.—Present Wilfred Lewis in the chair; present, 53 members and 4 visitors.

The Tellers announced that the following gentlemen had been elected Active Members of the Club: Messrs. J. F. Stevens, Carl G. Barth, Edward G. Bennett, George H. Perkins, A. J. Menocal, Benj. Smith Lyman, and F. M. Smith.

On motion of Capt. Spencer C. McCorkle, the Chair was directed to appoint a Committee of three, to propose measures for bringing the subject of Land-locked Navigation before the Boards of Trade and other commercial bodies of the principal Eastern and Southern seaboard cities, with a view of preparing a joint memorial for presentation to Congress, urging the importance of the subject and praying that the necessary preliminary steps be taken in that direction. The Chair subsequently appointed Messrs. McCorkle, J. Foster Crowell and Rudolph Hering as the Committee.

Hon. B. E. Fernow, Chief of The Forestry Division of the Department of Agriculture, described the tests of timber now being made under the auspices of that Department, and urged the necessity for them.

The matter was discussed by Mr. E. E. R. Tratman, visitor, and by Mr. T. Carpenter Smith, and a letter from Professor J. B. Johnson, who is in charge of the work, was read.

On motion of Mr. John C. Trautwine, Jr., the Secretary was requested to write to the Secretary of Agriculture a letter expressing the Club's appreciation of the importance of the tests described.

Mr. F. H. Lewis presented a paper upon Soft Steel in Bridges, accompanied by a series of Specifications for First-class Bridge Superstructure.

The subject was discussed by letter by Messrs. C. S. Sims, Jr., and Chas. S. Churchill, and verbally by Messrs. Henry B. Seaman, E. E. R. Tratman and James Christie.

Regular Meeting, November 7, 1891.—President Wilfred Lewis in the chair; present, 50 members and 5 visitors.

Mr. Max Livingston read a paper entitled "Some Comparisons as to the Relative Value of Solid, Liquid and Gaseous Fuel," which was discusssd by Messrs. James Christie, Carl Hering, Henry G. Morris and T. Carpenter Smith, and the author.

The Secretary read, for Mr. W. W. Thayer, a paper on "Street Paving, Its Cost, Character and Construction," which was discussed by Messrs. Philip D. Borden, Edward Samuel, Rudolph Hering, James Christie and George A. Bullock.

Business Meeting, November 21, 1891.—President Wilfred Lewis in the chair; present, 60 members and 8 visitors.

In the absence of the Secretary, Mr. F. H. Lewis acted as Secretary pro tem.

The Secretary pro tem. read the following communication:

To the Officers and Members of the Engineers' Club of Philadelphia.

Gentlemen: I hereby respectfully tender my resignation as Secretary of the Club, to take effect at the end of this month. My professional business is of a character requiring much traveling, and, as now arranged, the fixed engagements of your Secretary are too exacting.

I need hardly say that I resign with great regret.

I have but one request to make, and that is that my friends in the Club will give the same generous and hearty support to my successor as they have always given to me.

While I resign from the office of Secretary, I by no means relinquish my interest in the Club, and I intend to be one of its most active members.

Respectfully,

HOWARD MURPHY.

On motion of Mr. E. V. D'Invilliers the resignation was accepted.

The resignations from Active Membership of Messrs. John Mullen, Chas. M. Jarvis, Percival Roberts, Jr., Axel S. Vogt and Chas. A. Young were read and accepted.

A memorial upon the death of Moncure Robinson, Honorary Member of the Club, prepared by a special committee appointed by the Board of Directors for the purpose, was read by Mr. Thomas M. Cleeman, Chairman of the Committee.

The Tellers of Election reported that 109 votes had been cast and that the following gentlemen had been elected members of the Club: Messrs. Henry Farr DePuy, H. Warren K. Hale, William M. Kerr, William W. Nichols, Horace E. Frick, Rudolph Boericke, F. E. Richardson, George W. Irons and Wm. Swift.

The Treasurer reported that a number of names of members in arrears had been stricken from the list of members, in accordance with the By-Laws.

On motion of Capt. S. C. McCorkle, Chairman of the Committee on Land-locked Navigation, it was ordered that two additional members be appointed upon that Committee, and the President afterward appointed Professor L. M. Haupt and Lieutenant-Commander Wm. Swift as these members.

Mr. E. V. d'Invilliers raised a question as to the status of papers presented by non-members. The subject was discussed by Messrs. Robert W. Lesley, E. V. d'Invilliers T. Carpenter Smith and H. W. Spangler, and the Committee on Information and Entertainment decided to withhold for the present the paper on the Portland Cement Industry in Europe and America, presented by Mr. Pierre Giron and announced by that committee for this meeting.

Mr. Percy T. Osborne presented pamphlets on "Roads Improvement" and "The Gospel of Good Roads," published by The League of American Wheelmen, and an editorial in the *Philadelphia Record* of November 14, 1891, upon "Good Roads as Investments."

An article on "Rubble Stone Pavement," by J. Francis Le Baron, C. E., in the *Florida Times-Union*, was also contributed.

Mr. W. W. Thayer, continuing the discussion of his paper on Street Paving, replied to the remarks of Messrs. Borden, Samuel, Rudolph Hering and Bullock.

Mr. Walter Brinton read a paper on Street Paving.

Professor L. M. Haupt exhibited a map of Philadelphia, showing the character of the paving of its various streets.

Mr. R. W. Lesley read a paper on Purchasing Cement for Large Work.

BUSINESS MEETING, DECEMBER 5, 1891.—President Wilfred Lewis in the chair; about 70 persons present. The following nominations for officers for 1892 were made and seconded:

For President.—James Christie.

For Vice-Presidents.—(Two to be chosen) Frederick H. Lewis, Howard Murphy, Pedro G. Salom.

For Secretary.—John C. Trautwine, Jr.

For Treasurer.—T. Carpenter Smith.

For Directors.—(Six to be chosen) John E. Codman, George V. Cresson, Strickland L. Kneass, Wilfred Lewis, M. Richards Mucklé, Jr., H. W. Spangler, David Townsend.

A telegram was received from Mr. Howard Murphy, stating that he would be unable to bring up the consideration of the social feature, and asking its postponement.

On motion of Professor H. W. Spangler, the question of appointing a committee to confer with the municipal authorities in preparing specifications for street paving, as suggested by Mr. Edward Samuel, was deferred until Mr. Samuel could be present.

At the request of Mr. E. V. d'Invilliers, who was unable to be present, the question of the status of papers from non-members was deferred.

The resignations from Active Membership of Messrs. O. B. Colton and Samuel Tobias Wagner were read, and action upon them deferred under the rules.

The Secretary announced that the Club House had been connected with the Bell Telephone Exchange, Telephone No. 3440.

The Committee on Land-locked Navigation submitted preambles and a resolution expressing the gratification of the Club at the general awakening to the importance of the subject, and promising its best efforts to further the movement. The Committee also submitted a form of letter transmitting the foregoing to the Boards of Trade and other commercial bodies of the Eastern and Southern seaboard cities, to be accompanied by a digest of the route proposed and by copies of such other papers as may be necessary to properly present the subject.

Mr. F. H. Lewis' Specifications for First-class Bridge Superstructure, submitted at the meeting of October 17, were discussed by written papers from Messrs. W. H. Burr, Palmer C. Ricketts and Alfred E. Hunt, non-members.

The Secretary read a paper by Mr. Geo. R. Ide, upon Smoke Prevention or Abatement, and a letter from Mr. Russell Thayer upon the same subject.

The discussion was continued by Messrs. George S. Strong, Max Livingston, H. W. Spangler, T. Carpenter Smith and Henry G. Morris, members, and by Messrs. John T. Baltz and Walter C. Kerr, visitors.

The Secretary read a paper upon the subject, by an ex-member of the House Committee, who directed his remarks to the smoke emitted by the pipes and cigars of the members at meetings.

Business Meeting, December 19, 1891.—President Wilfred Lewis in the chair; about 60 persons present.

On motion of Mr. Howard Murphy it was ordered that a Club Committee of at least nine persons, none of whom should be members of the Board of Directors, be appointed by the Chair, to consider and report upon the best means of advancing the social feature of the Club.

The Secretary read a letter from Mr. George A. Bullock, Chief of the Bureau of Highways, in reply to a question as to the attitude of the municipal authorities in the matter of a proposed committee of the Club, to co-operate with them in framing specifications, stating that while the Department of Public Works would

at all times be glad to receive suggestions or recommendations that would increase the efficiency of its work, he hardly thought it proper to ask the co-operation of the Club in forming specifications; also a letter from Mr. Edward Samuel regretting his inability to be present at the meeting, and submitting that his suggestion in the matter be dropped. No action was taken.

On motion of Mr. Howard Murphy, it was directed that it be made a rule of the Club, that papers and other literary communications from non-members may be announced by title only, but shall not be printed, either in full or in abstract, prior to their presentation at a meeting.

On motion of Professor L. M. Haupt, the Publication Committee was requested to consider the propriety of printing papers and abstracts of papers from members on separate sheets of a different color from that of the meeting notice.

Mr. E. V. d'Invilliers submitted a proposed amendment to the By-Laws, providing for the appointment, by the Chair, of a Nominating Committee, whose duty it shall be to prepare from the nominations made at the Business Meeting of the Club, held on the first Saturday in December, a "Club Ticket," "which, so far as is practicable, shall contain one nominee from at least three of the engineering branches eligible to membership."

Two resignations from membership, presented at the last Business Meeting, and three now presented for the first time, were properly referred.

The Secretary read the following:

PHILADELPHIA, December 17, 1891.

Mr. John C. Trautwine, Jr.,
Secretary, Engineers' Club of Philadelphia.
1122 Girard Street.

DEAR SIR: Acknowledging the receipt of a communication from you, wherein you state that I have been nominated for the office of Vice-President by Messrs. Edwin F. Smith and S. M. Prevost, I would say that while I highly appreciate the kindness and consideration of these gentlemen, I have decided to decline the nomination.

Yours truly,

HOWARD MURPHY.

The Secretary read a paper entitled "The Proposed Boulevard for Philadelphia, and its Cost," by Mr. W. W. Thayer. The paper was discussed by Professor L. M. Haupt.

The Secretary read, for Professor H. W. Spangler, a paper upon "Tests of Heated and Headed Wrought-Iron Bars."

Mr. Jacques W. Redway presented an elaborate paper upon the Practical Projection and Construction of Maps, and briefly described its salient features.

GEOLOGICAL SURVEY OF N.J.
ROOM 18, 4TH FLOOR,
POST OFFICE BUILDING,
PHILADELPHIA.

PROCEEDINGS

OF THE

ENGINEERS' CLUB OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. IX.] APRIL, 1892. [No. 2.

ANNUAL ADDRESS

OF

WILFRED LEWIS, Retiring President.

Delivered January 16, 1892.

GENTLEMEN,—We meet to-night, not only to elect officers for the coming year, and transact such business as may come before us, but to inaugurate, as I believe, a new era in the prosperity and growth of the Club. During the fourteen years of our organized existence, there have been periods of activity and depression; and although we may, in our earlier youth, have grown more rapidly in size than we seem to be doing at present, I think it must be apparent to all that we are now beginning to grow in unity and strength, and at no other period has the interest manifested in our Proceedings and Club life been so intense. The change may be traced at first to the adoption of our new Constitution and By-laws; afterward to the energy and devotion with which the various committees of the Board have discharged the duties imposed upon them; and last, but not least, to the cordial co-operation of the whole membership in the efforts made to advance the interests of the Club.

Good rules are important and desirable, but success depends upon something more, and it has been my good fortune during

the past year to be surrounded by strong and earnest workers, who, I rejoice to say, have given the Club a new start in life. We will begin the New Year as a corporate body and look forward to many happy reunions like the present under constantly improving circumstances; but it is my privilege as retiring President to deal more particularly with the past, and remind you of some of the engineering features that have marked our recent progress. It must not be expected that full justice to the subject will be accorded within the proper limits of an address of this character, or that one so engrossed by professional duties requiring close attention will be able to observe the general drift and importance of events which should be viewed at a greater distance to be rightly comprehended. It is probable, therefore, that I may give undue prominence to matters in which my own interests are chiefly centered, and neglect or pass over too lightly those in which the engineering profession is more generally and deeply concerned.

So vast has the field of engineering become, and so rapid are the changes taking place, that it is impossible to realize at once their full importance. Discoveries and inventions, which seem at first trifling and unimportant, may develop applications which will revolutionize the world; while many others, often full of promise, are superseded in a short time, and relegated to the follies of the past. But all are steps in the progress of the age, whether leading to success or simply pointing out the rocks to be avoided, and it can hardly be doubted that this progress is far greater than we appreciate while moving in the current without reference to the landmarks that are passing by.

The great resources of nature, commonly supposed to be inexhaustible, are being taxed, as never before, for the benefit of man, and especially for the present generation, without much regard for the future. New storehouses of energy, capable of building all the wonders of the ancient world, with not a tithe of their labor and expense, are complacently unlocked to actuate modern appliances in the performance of useful work, or for the maintenance of luxurious ease, while the ashes pass on to posterity without hope of regeneration for future use.

In this respect the civilization of the nineteenth century differs

radically from that of any previous age, and much serious reflection has been given to the inevitable result of our wonderful progress, leading as it does to greater and higher heights, and depending as it does upon a crumbling and burning foundation of coal.

Whether the structure will be ultimately undermined and fall is a question I cannot presume to answer, but for two or three generations, at least, it seems destined to grow and prosper almost beyond conception.*

The most recent estimate of the time required to exhaust the coal-fields of North America at their probable rate of consumption indicates that in about 112 years there will be very little left, and that the time is almost at hand when serious inconvenience will begin to be felt from the increasing scarcity of coal. All this does not immediately concern us, but it will certainly be a matter of vital interest to coming generations, and, to make our work as engineers of permanent benefit, we cannot look too closely toward the foundation on which it rests.

The sudden growth and popularity of electricity as a light-giving agent, and its wonderful development in the transmission of power, have been estimated to have caused the consumption of power to have doubled in the last seven years.

Owing to the increasing efficiency of prime movers at the same time, and to other economical means developed to prevent waste of fuel, it may be assumed that the consumption of coal has not kept pace with the increasing consumption of power; but, however much economy may be gained in the conversion of heat into power, it seems safe to predict that the output of coal will

* This estimate of General Isaac J. Wistar is based upon the actual known rate of increase in coal consumption at the present time, which is about 100 per cent. per decade, and he has assumed, in arriving at the above figures, that this rate will continue for the next thirty years, then drop to 50 per cent. per decade for the next forty years, and finally to 33⅓ per cent. per decade for the last forty-two years. It also appears from his estimate that the entire quantity of coal available in North America is about 673,000,000,000 tons, which, at the present rate of consumption, would last about 4,500 years. We are therefore just beginning to draw upon our supply; and although a continual increase in consumption to the end of the coal-burning age may be questioned, the indications are that this age will mark a comparatively short period in the history of civilization.

steadily increase until the supply begins to fail, or, in other words, that economy of coal will continue to mean more power rather than less coal, and that, whatever may be achieved in the future, either by the conservation of the latent heat of steam, or by the much-hoped-for direct conversion of heat into electricity, the "bottled-up sunlight of ages" will continue to melt away with unabated freedom.

But little success has ever attended any effort to draw directly from the great fountain-head of energy, whose light and heat alone can give a permanent basis to engineering progress, or rather as permanent a basis as can ever be hoped for. Indirectly, through the natural forces of wind and water, the energy thus poured upon the earth has certainly been utilized to a small extent through an indefinite period of time; but a power so diffuse, although indefinitely greater in amount than any other known, has not been found available for modern requirements. That it may ultimately be turned to account when necessity requires it, is a possibility that relieves in a measure the gloomy prospect of dependence upon the unprecedented destruction of natural resources now in progress. That it will be turned to account while such resources are at hand in abundance is hardly to be expected, but its consideration seems at all times deserving of attention by engineers.

We cannot delay that distant period when the earth, as astronomy teaches, will be as dead as the moon, and the day will be a year in length; but we may do something to prolong to mankind the benefits which we now enjoy. Life depends upon a flow of energy, and is only possible while the great clock of nature is running down; but it is within the power of man to regulate the artificial flow, which is now running faster than ever before, and it is to be hoped that some method of re-winding from the great mainspring of our system will in time be discovered.

Ericsson's labors in this direction demonstrated the possibility of a solar engine, and dealt with the problem in a practical way, but nothing of commercial value has ever resulted.

Others have sought to discover new forces in nature, which have only to be tapped in the right way to obtain an inexhaus-

tible supply of power, and the claims for such discoveries have found ready and strong adherents among credulous enthusiasts, but there seems little ground to hope that the solution of this question will ever be brought about by the discovery of a new and costless power, whether it be "sympathetic vibration" or the ten-thousand-foot tons of energy now said to be locked up in every cubic foot of ether. For want of an outlet, enormous quantities of energy remain locked up in the ocean; and although cheap power is our greatest need, it is not to be expected that we can ever get something for nothing, even from nature.

The examples of costless power already existing, including sunlight, wind, wave and tide, are all languishing, because it costs more to utilize them than to profit by the energy stored in coal. A cheap method of utilizing these forces of nature would certainly add to the permanent character of our present achievements, but there is no reason to believe that a new form of costless power will be any more available than the older forms with which we are already familiar, and alleged discoveries of latent energy may easily be true without being of any practical value.

The sudden development of steam power, with its introduction on land and sea, seems to have obscured for a time the advantages of slower and cheaper methods of transportation, and it is now interesting to observe that sailing vessels are again coming into favor in Great Britain, a strong interest in canal construction is awakening in this country, and good wagon roads, as well as railroads, are commanding a share of public attention. This seems to indicate a coming era of cheaper transportation, which should receive the cordial support of engineers, whose province it is to conserve natural resources, as well as to expand the application of power to the service of man.

Of the great canal enterprises which are now in progress the Nicaragua project must be regarded as the most important to this country and the whole world. That it should be pushed to completion by the Government and people of the United States is clearly set forth in the Annual Message of President Harrison. This important Message has been so recently delivered, and so well received by commercial bodies and the press of the country, that it seems unnecessary to do more at present than to mention

the fact that considerable work in preparation and in construction has been accomplished during the year just closed. To judge from the great success of the Suez Canal, and the enormous tonnage likely to pass by the way of Nicaragua, it seems probable that a good return might be realized from a much larger original cost, and it is of interest to note that the income from the Suez Canal is now twenty-three per cent. of the original capital represented by the 400,000 shares.

The Manchester Ship Canal is still in progress, and new estimates for its completion have been made. The work has already cost about $52,000,000, or nearly double the original contract price, and it seems probable that not less than $15,000,000 more will be spent upon it. The excavation in this gigantic work amounts to 46,500,000 cubic yards, of which 10,000,000 are sandstone rock, and the removal of the material is progressing at the rate of 1,000,000 cubic yards a month. To reduce the cost of labor and hasten the completion of the work, mechanical appliances have been used on the largest scale, and these may be summarized from a paper by the Engineer-in-chief to consist of 97 steam excavators, 8 powerful steam dredges, 173 locomotives, 6,300 trucks, 288 miles of track, 124 steam cranes, 192 portable and other engines, and 212 steam pumps. Ten thousand tons of coal per month are consumed in the operation of this plant, and not more than 17,000 men and boys have ever been employed on the canal at one time.

A new St. Lawrence canal, 13¾ miles long, between Lake St. Louis and Lake St. Francis, has been decided upon by the Dominion Government. It will be designed for vessels drawing 14 feet of water, and the estimated cost for a width of 100 feet is $4,750,000.

The advantages to be derived from inland navigation in times of peace and war have been so clearly presented at our meetings during the year just closed, and the importance of such communication from New York to the Gulf of Mexico is so apparent, that I need only mention the subject as one which is likely to be brought before Congress at an early date.

From the report of the recent Waterway Convention at Detroit, it is also probable that bills looking to the improvement of

lake navigation, and the construction of a ship canal 20 feet deep from Lake Erie to the seaboard will come before the present session of Congress.

The Mexico Drainage Tunnel, reported to have been abandoned about a month ago on account of excessive quantities of water encountered in the shafts, will probably be continued when a new contract, covering the expense of additional pumping machinery, with a partial indemnity for the loss incurred, is consummated. In two years the contractors have completed 6,885 feet of tunnel, and 21,810 feet remain to be driven. The total length when finished will be about six miles.

The St. Clair Tunnel, between Sarnia, Ontario, and Port Huron, Mich., which was begun in July, 1889, and completed in August of this year, shortens the time between Chicago and eastern points, over the Grand Trunk Railway, by about two hours. It was driven from both sides of the river through blue clay and quicksand; and notwithstanding the difficulties encountered in the latter, it was pushed to completion through a distance of 6,026 feet under the river, or 11,553 feet including approaches, in the short space of twenty-six months, and at a total cost of $2,000,000. The tunnel is a continuous iron tube, 20 feet in diameter, weighing 28,000 tons, and is laid at a depth of about 40 feet below the surface.

Work on the tunnel for the Niagara Power Company has advanced steadily, and the last reports show a progress of 4,733 feet in thirteen months. It is expected that the remaining 1,967 feet will be completed about next August. The success of the project is so well assured that the extension of the tunnel has been already determined upon. The completion of this enterprise is full of interest, not only as the greatest water power in the world, but also for the practical demonstration anticipated in the transmission of power. A certain amount of the 120,000 horse-power available will be sold directly to local mills, but a more distant market will have to be found for the greater portion of it, and the mediums selected for its transmission, electricity and compressed air, will be studied side by side. The company propose to move slowly in this direction until the merits and defects of the two systems are clearly demonstrated. A great advantage in

the use of compressed air, besides its economy of transmission, is found in its perfect adaptability to existing plants where steam engines are employed, and, as is well known, the economy of transmission can be vastly increased by a slight expenditure of heat.

In this connection, Prof. Coleman Sellers has suggested that the air be heated by a flame burning directly in the flow of compressed air to the engine so that the products of combustion may add to the volume of the working gas, while the heat of combustion is all retained. This ideal power, planted, it would seem for all time, and dependent upon nothing but solar energy, is estimated to yield a horse-power with profit at $10 a year, and it may in time be developed by future constructions to the enormous capacity of four or five million horse-power. Thirty or forty such tunnels as are now under construction would drain the Falls, and possibly some of us may live to see Niagara turned on and off for visitors like the falls in Watkins' Glen. Stranger things have happened, and there seems to be no reason why the whole of this power should not be turned to account.

The railway construction during the past year shows less mileage than any year since 1885. But little more than 4,000 miles have been built, and the total amount is now about 171,000 miles. Railway construction seems to have been overdone for a time, but the comfortable financial outlook at present encourages the hope that renewed activity in this and other directions will be witnessed during the coming year.

But, if we have not gone as far as usual in the construction of railroads, it may yet be said we have gone higher, until in July last a locomotive reached the summit of Pike's Peak at an elevation of 14,147 feet. The line of this road is about 8.75 miles in length, and starts from Colorado Springs at an elevation of 6,000 feet, which is but little less than the summit of Mt. Washington, and rather more than the summits of other prominent mountain railroads.

Although comparatively little progress is to be noted in railroad construction, it is interesting to observe the advance in better equipments, terminal facilities and higher speeds that have been made during the year.

The new train-shed of the Pennsylvania Railroad at Jersey City is an imposing structure 252 feet span, by 652 feet in length, and is covered by one of the largest, if not the largest, roof in the world. The terminals at this point have been four years under construction and are now almost completed.

The Reading terminals in this city are also making rapid progress, and the appearance of desolation along their right of way is beginning to be relieved by indications of the great improvements that are soon to follow.

In the matter of speed, the highest recorded during the year was made August 27 between Philadelphia and Trenton on the Philadelphia and Reading Railroad. On this trip the train consisted of three cars about equal in weight to the engine and tender, and the remarkable rate of 90.5 miles per hour was at one time attained. This broke the previous record of 86 miles per hour, held by an English compound, and the speed is the more remarkable for having been made with comparatively small drivers, making 7.5 revolutions per second, with a piston speed of about 1,800 feet per minute.

In regular running time the New York and Buffalo Express has made an advance to over 50 miles an hour, including stops, and is now the fastest train in the world. This increase in speed has become possible by improved roadbeds and heavier rails, and it is now confidently predicted by an eminent railroad authority that still higher speeds may be expected as more efficient engines and lighter cars are developed, and more perfect protection against accidents is established.

The weight of passenger cars certainly seems out of all proportion to the load to be carried, especially that of the more luxurious sort in which 8 to 10 per cent. of the weight of the car represents its full load, and when it is considered that freight cars often carry two or three times their own weight, the margin for improvement ought to be encouraging to inventors.

Compound locomotives have grown rapidly in favor during the past year, and some notable results on different styles and makes have been published. A very interesting account of the performance of four compounds on the East Tennessee, Virginia and Georgia Railway for a period of ten months showed

that, in comparison with simple engines doing the same duty, a saving of 25 per cent. in coal was effected. From other tests on similar engines, the saving in coal has been rated from 14.52 per cent. to 28.63 per cent., and even 37.7 per cent. has been given; but the result obtained depends so largely upon the service demanded that the most reliable figures would appear to be those determined from regular service over a considerable period of time, and 25 per cent. seems to be a fair average for usual conditions.

Assuming the average consumption of coal in simple engines to be 1,000 tons a year, and the cost of conversion from simple to compound at $1,000, it is evident that the railroads cannot afford to throw away annually enough coal to pay for the change, which seems destined to become general.

Besides the saving in coal and water, there are also other advantages claimed for the compound, which will be appreciated by the traveling public. It is said to offer a satisfactory solution to smoke abatement, so recently discussed at our meetings, while the draft is steadier, and the noise from the blast less deafening.

Another style of compound, invented by Mr. S. M. Vauclain, the Superintendent of the Baldwin Locomotive Works, has also come prominently into service. This engine is a radical departure from all previous types, a high and low pressure cylinder being used on each side of the engine, to actuate the same cross-head, and the simplicity of the valve admitting steam to both cylinders is a noticeable feature. The performances of this engine compare very favorably with those of other types, and, under certain conditions, an actual saving of 53.5 per cent. in fuel has been claimed.

To illustrate the growing demand for compound locomotives it may be said that in 1890 this firm built three compounds out of a total of 946, while in 1891 they built 82 compounds out of a total of 899, and have now orders for some 40 new compounds.

The objection originally urged against the eccentric loads brought to bear upon the cross-head of the Vauclain locomotive by unbalanced pressure on the two pistons has not been found in actual practice to be of any moment, and the increased weight in reciprocating parts has been much less than might have been expected.

On the new compound for the Royal Blue express, the reciprocating parts, including one-third of the main rod, weigh 1,155 pounds, while on an equivalent simple engine of the same class this weight would be 1,040 pounds, showing a difference of only 115 pounds. This compound has attained a speed of 77 miles an hour, which corresponds to about six revolutions per second of its six-foot drivers, and a rough estimate of the inertia of the reciprocating parts at this speed indicates about 51,000 pounds of unbalanced inertia to be taken care of on each side of the engine. As usual, part of this inertia is taken directly by the drivers and part by the engine as a whole, the distribution being estimated from the weights and counterweights employed, at $\frac{3}{4}$ on drivers and $\frac{1}{4}$ on the engine as a whole. This distribution, as would naturally be expected, makes a very steady engine at high speeds, but it also requires a very substantial roadbed to withstand the variable pressure on the rail, occasioned by the excess of counterweight.

The problem of counterbalancing for an indefinite increase in speed is apparently still as far from solution as ever; and when we consider in the present case that an average load of 17,000 pounds on each driver varies, at 77 miles an hour, from 4,000 to 30,000 pounds six times a second, the limit of speed would seem to be very nearly reached. The remedies proposed for this defect in the high-speed locomotive have generally been regarded as more objectionable in other ways than the defect itself, and, as piston speed is also limited by the ability to dispose of the exhaust steam without serious loss from back pressure, the problem of obtaining still higher speed seems to depend mainly upon the size of drivers employed.

In compound locomotives, the back pressure affects the efficiency more than in simple engines; and although the compounds are able to show considerable economy over simple engines in high speed service, their greatest advantage is seen in engines designed for heavy freight traffic, as an example of which, the Decapods, just finished by the Baldwin Locomotive Works for the New York, Lake Erie and Western Railroad, may be mentioned. These are the heaviest engines yet built by that firm, and weigh in working order over 100 tons.

An interesting episode in the history of railroading occurred on the 12th of November last at Bordentown, N. J., to commemorate the sixtieth anniversary of the first movement of trains by steam upon a railroad in New Jersey. On this occasion a suitable granite monument was erected by the Pennsylvania Railroad to mark the first mile of track laid, and this was formally transferred to the custody of the Camden and Amboy Railroad Company. The guard-rail at the base of the monument and the stone supports were relics of the original track by which passengers were taken from Bordentown to Amboy in the remarkably quick time of from six to seven hours, or from Philadelphia to Bordentown by boat and thence to New York in the same day. Tedious as this rate of travel may seem at the present time, it was a great step in advance of previous facilities, of which the advertisement of 1751, referred to by the orator of the occasion, is a good illustration. At that time, only 140 years ago, passengers were conveyed by "stage boat" from Philadelphia to Bordentown, thence by "stage wagon" to Perth Amboy, and thence by another well-fitted stage boat to New York, covering the entire distance in three days and a half, which according to the advertisement of the time was then believed to be by thirty or forty hours the fastest time yet made.

In improved facilities for local passenger traffic, the development of electric street railways is most remarkable. The capital invested in this way in the United States and Canada is now estimated at $75,000,000, while but a few years back, not longer ago than 1886, electric railways were in a doubtful and experimental stage of existence.

Recent statistics show 11,029 miles of street railways, of which 6,442 are operated by horses, 3,000 by electricity, 1,918 by steam and 660 by cable power, while in the last year the number of horses employed has fallen from 116,795 to 88,114.

The relative economy of the different systems depends upon so many circumstances and conditions that exceptions can always be found to any general deduction. Cable roads seem to have the advantage in districts of dense population where steep grades are encountered, although the first cost is greater; but for the usual conditions of suburban traffic the trolley system of electric propulsion is at present the most successful.

The storage battery offers in many ways such decided advantages over other traction systems that it is to be hoped the efforts made in this direction will finally be successful. The cost of operating by this system is now estimated on comparatively level roads at about the same as horses, but it is encouraging to note that prominent manufacturers of storage batteries are willing to guarantee their cost of renewal on terms which will insure the companies using them against loss in case of failure to meet the requirements demanded.

The trolley system in Boston has worked so well that the West End Company is putting in a greatly enlarged plant to be driven by 13 triple expansion engines of 2,000 horse-power each; but in many sections, and particularly here in Philadelphia, the opposition to overhead wires is strong and unrelenting, and something better is confidently hoped for.

In some respects, cable traction has been an improvement on horse flesh, but it is not by any means the ideal system that some of its advocates would have us believe, and to a Philadelphian who has experienced the annoyances of the system in all their fulness, the following summary of its advantages as stated at a meeting of the American Street Railway Association seems rather amusing.

Without giving all the points of merit, the advantages of cable traction were claimed to consist, practically, in its trustworthiness and independence of climatic conditions, personally in being agreeable to the public in point of comfort, convenience, accommodation, safety and quietness, and sanitarily in the negative gain of contributing no nuisance, and the positive gain of facilitating drainage. The advantage of the slot for removing horseshoes and testing carriage wheels was not mentioned, nor the healthful exercise obtained by swinging on straps as the car lunges in its course, but the sanitary effect of an open sewer in the middle of the street is thought to be a point not generally known.

Much light on the rapid transit problem may be looked for in Chicago during the coming World's Fair, and great activity in this direction is manifested. The location of the Fair being seven miles out of town will necessitate unusual facilities for handling such large numbers of people, and elevated and sur-

face roads of all descriptions, together with steamboats, will be in operation. A motor car operated by ammonia is said to be already on the grounds. This motor derives its power from anhydrous ammonia at a temperature of 80 degrees Fahrenheit, the vapor of which is absorbed by water after passing through the engine, and the actual cost per car mile is given at 3.2 for motor alone, or 1.1 cent per car mile for the motor and four cars.

The movable sidewalk with platforms running at three and six miles an hour will also be in operation, and even cars with sails for running over the prairies are said to be contemplated.

Interest in the Columbian Exposition of 1893 has grown rapidly at home and abroad during the past year, and the project may now be considered an assured success. The site selected comprises two large parks and an intervening strip, covering a total area of 1,037 acres. The Exhibition buildings will be situated in Jackson Park on the Lake front, much of which is newly-made land. The main building, 1,688 feet long by 788 feet wide, covers an area of 30.5 acres, or 50 per cent. more than the main building of the Centennial. The other department buildings will cover an area of some 74 acres, and the stock sheds about 40 acres. In additon to this, the United States Government pavilion will cover an area of 3.4 acres, and the model battle ship of the United States Navy Department in the Lake about 0.2 acre.

The total area covered by buildings will not be less than 150 acres, and numerous annexes and smaller buildings may be expected as the work progresses. The cost of all these buildings is estimated $7,000,000 which seems a low figure when it is remembered that the Centennial buildings, covering but 48.5 acres, or less than one-third the area, cost nearly $4,200,000. Deducting the 40 acres of stock sheds, the scale of the enterprise is still seen to be more than double that of the Centennial, and the grounds inclosed are nearly four times as great in extent.

It has been asserted that a tower 1,150 feet high would be one of the features of the Fair; but at present this point seems to be in abeyance, and it is to be hoped that something more original in its conception will be adopted.

The rival Hudson River Bridge companies have attracted con-

siderable attention of late, and the formality of breaking ground has been chronicled with great enthusiasm by the New York and New Jersey Bridge Company, which, it appears, has good right to break ground, but no right to cross the river. The estimates of cost by the different plans proposed vary from $40,000,000 to $70,000,000. The boldest design, contemplated by the North River Bridge Company, is that of Gustav Lindenthal, who proposes to cross the river by a single span 3,100 feet in length, using four suspension cables over five feet in diameter. The structure is intended to carry 14 tracks, and the cost per foot of track is claimed to be less than that of any of the great bridges in this country or abroad.

The mineral statistics for 1891 show, for this country, a large increase in production of aluminium, anthracite coal, copper, silver, lead, petroleum and zinc, with a falling off in pig iron, nickel and asphaltum.

The production of gold has remained nearly constant at $33,000,000 per annum for the last ten years. The output of bituminous coal amounted last year to 98,000,000 tons, or about the same as in 1888, and the combined product of bituminous and anthracite was 1,384,000,000 tons. As a coal-producing country we are exceeded only by Great Britain, whose output in 1890 was 1,845,000,000 tons, and, in view of the figures presented by General Wistar in his recent address before the Academy of Natural Sciences, it may be regarded as a matter for congratulation that we are not as a nation at the head of the list in the production of coal. We can well afford to let other nations run through their inheritance of this all-important mineral, for they who mine it last will surely do so to their best advantage, and, as the facts appear at present, we cannot begin too soon to guard it.

This is an engineering problem with great political consequences, which looks beyond our immediate interests to the welfare of the nation in the near future, and I believe it deserves more attention than we have generally been inclined to bestow upon it. It was at one time said, very truly, in the face of bitter opposition, "If the country will build the railroads, the railroads will build the country;" but it begins to appear they will

not keep it built forever, and, before many years, possibly within the lifetime of some of us, it may be realized that coal will save the nation that is wise enough to save its coal.

I do not mean by this to discourage enterprise, but to encourage economy in its prosecution, with something more than immediate gain in view. Perhaps this is too much to expect from a nation of freemen bent on the main chance; but while we are climbing to the pinnacle of fame and fortune, let us consider the descent to be made on the other side, and soften its ruggedness while we may.

But we must progress or fall behind, and while we are moving on, it is gratifying to know we are in the lead; so, for the present, at least, however we may differ in regard to ultimate ends and aims, it is certainly encouraging to note the strides we have made in the various industries which go to augment our wealth and power.

Our production of pig iron last year was about the same as that of Great Britain, while in 1890 we exceeded for the first time in our history the output of that country in this important product, and the indications are that hereafter we will remain in the lead. The falling-off last year in pig iron corresponds to the reduction in the output of steel rails, which suffered a decline of nearly 50 per cent.

The production of aluminium has increased from 94,881 pounds in 1890 to 163,820 pounds in 1891, while the price has declined from $2 to $1 per pound. Since 1888 the production of this metal has increased eightfold, while in the same time the price has declined almost as rapidly as the increase in production. It is said to have been sold during the past year at 75 cents per pound, and even as low as 50 cents, and the price abroad is now quoted at 50 to 60 cents per pound. There is no doubt that it can now be produced for 50 cents a pound with profit in this country. A large item in the cost of production by electrolysis is power, and where this is cheap aluminium can be cheaply made. It is well known that 10 horse-power will separate a pound of metal every hour, and now that the problem of cheap aluminium has been practically solved, the question is what to do with it. It is valuable as an alloy with copper, but the great

expectations of its utility as a metal for general use seem to have suffered a gradual decline. It is light, but not very strong, insoluble in many strong acids, but easily attacked by greases and alkalies, and behaves very strangely in salt water, where a white flocculent powder is formed with the liberation of gas. It is, therefore, not adapted for household utensils, or for the construction of sea-going vessels, but it may be used in fresh water, and a steam launch of aluminium is said to have been placed on one of the Swiss lakes. It has been suggested as a suitable material for the construction of cars for aerial navigation, and, in that field, the outlook is not without promise.

Considerable scientific progress has been made in aerodynamics by the experiments of Prof. Langley on the sustaining power of aeroplanes, while moving at different inclinations and speeds. At an inclination of 2 degrees to the direction of motion, and at a speed of $44\frac{3}{4}$ miles an hour, it was found that 209 pounds could be sustained by an effort of one horse-power. This result has been questioned on theoretical grounds, but Mr. Maxim claims that even better results can be obtained. It is well known that one horse-power can be stored in much less than 209 pounds of material, and the ability to soar by mechanical means can no longer be regarded as improbable.

The Report of the Secretary of the Navy for 1891 shows very marked progress in the reconstruction of our navy. During the year four new vessels have been placed in commission, making a total of 13 since March, 1889, and 23 other war ships are under consideration. It is expected that all of these vessels will be finished within three years.

In armor plate, most admirable results have been obtained by the use of nickel steel treated by the Harvey process, and in armor-piercing projectiles the advance made during the year is even more encouraging. The secretary states that until last year the United States was entirely destitute of armor-piercing projectiles, and that the difference in the effective force of the navy to-day, as compared with its situation a year ago, is incalculable.

The stimulus given to the iron and steel industries of the country, by the work of naval reconstruction, has now placed us in a position to fully equal and, in many cases, to excel the best examples of foreign skill in engines and munitions of war.

In machinery for heavy ordnance construction, the gun lathes now approaching completion in the works of Wm. Sellers & Co., Incorporated, and Bement, Miles & Co., will far exceed in power and conveniences for operation anything yet attempted. In the material required for these lathes, it may be mentioned that the lead-screws are so much longer and heavier than any bars previously rolled in this country, that great difficulty was experienced in inducing any of the steel mills to attempt to make the blanks. All refused to bid on round blanks, and but one concern, the Carbon Iron Co. of Pittsburgh, consented to make them square, and then only for steel low in carbon. Their success, therefore, in rolling a bar $6\frac{1}{4}$ inches square and 70 feet long, in a universal mill, is worthy of note. This bar was planed to remove the corners, turned to 6 inches in diameter, and threaded the entire length for the feed screw of the largest lathe. This lathe is capable of boring and turning a 16-inch gun 50 feet long, which will weigh, when finished, $111\frac{1}{2}$ tons. The face plate, a steel casting 8 feet in diameter, with teeth 4 inches pitch and $10\frac{1}{2}$ face, was furnished by the Solid Steel Casting Company of Alliance, Ohio, and is a fine example of the progress of the art of casting steel. Although I feel tempted to enlarge upon the subject of gun lathes, and have covered so little of the field in view, I will not tax your patience any further in the narration of facts and figures, which must be more or less familiar to you all.

In conclusion, I desire to thank you for your kind attention, and to express my appreciation of the consideration you have always shown me.

VII.

STREET PAVING—ITS COST, CHARACTER AND CONSTRUCTION.

By W. W. Thayer, Active Member of the Club.

Read November 7, 1891.

The street pavings of cities of the first class should be those best adapted, according to their durability, to the wear and tear not only of the travel to which they are subjected to now, but with a view to the future popularity of the street or road and its probability of being the course of *heavy travel* or simply the *light transient travel* of two-horse teams.

I have accordingly divided my subject into

(*A*) The Heavy Travel Roadways.
(*B*) The Light Travel Roadways.

Roadbed.

In both classes, whatsoever may be the future of the pavement, the same care should be taken in the construction of the roadbed or sub-grade; for the finest pavement, however costly, is worthless when laid on an improper or unstable foundation.

The character of the sub-grade foundation or stable support for our formed roadway should be most carefully examined, the presence of springs, and soft or soggy soil carefully obliterated and replaced with good, hard, dry earth, and the whole rolled before the placing thereon of one shovelful of gravel or binder. A well-compacted road or street cannot move in a lateral direction on account of its curb protection; it cannot move longitudinally on account of its own stability; but it can and will move downward unless the proper care be taken in the preparation of the roadbed. The motion, if any, will be uneven, causing cracks and ruts in the finished pavement, and, finally, be the cause of the total breaking up of the entire pavement at that point. The settling of the sub-grade at any point causes a depression of the finished surface immediately over it; this depression, when subjected to the tractive force of a wagon-wheel or a hoof, will cause the adjoining stones to tip up, and we have, in a short time, the hole, or wavy depression, so common on our city streets.

The Crown

Or water-shed of the roadway should appear on the finished surface only. Most specifications call for a crown in the construction of the sub-grade parallel to that of the finished grade. To this I most strenuously object. The roadbed should be excavated level, and the crown formed on the finished grade entirely. I have searched and inquired for some good reason for this common crowning of the sub-grade, and can only find one thing in its favor, and that is the question of surface drainage during construction, and we know how much the rough surface of a roadbed would lead off water on the slight grade allowed for a crown. Experience has taught us that water will not drain on a rough surface such as we would have on the sub-grade of our roadway. By the absence of the crown in the sub-grade an addition of two or three inches is gained in the center of the section, where naturally the travel, and hence the tractive force, is greatest, and where, consequently, the most wear and tear will be.

The rate of fall of the crown should vary with the character of the pavement laid. As in the case of (*A*) *Heavy Travel Roadways* the fall of the crown should be greater than that of (*B*) *Light Travel.* This is evident from the fact that in the first class (*A*) a surface must be drained which, in itself, is not homogeneous, but rather filled with solid interstices adapted for the adhesion of an animal's hoof in the hauling of heavy loads, while smoothness of surface is the aim on (*B*) *Light Travel Roadways.*

TABLE OF FALLS OF CROWN FOR VARIOUS ROADWAYS.

Pavement.	Fall not more than	Fall not less than	Average Fall per 100 ft.
Stone Block	6 in. in 13 ft.	3 in. in 13 ft.	2.00
Asphaltum	6 " " 15 "	3 " " 40 "	1.34
Brick	6 " " 10 "	3 " " 20 "	2.46
Macadam	6 " " 10 "	3 " " 30 "	1.85
Gravel	6 " " 10 "	3 " " 30 "	1.85

(*A*) The Heavy Traffic Pavement.

Such paving should be adopted for this class as is suitable only for the constant wear and tear of the heaviest kind of travel, the pounding of large omnibus lines, loaded drays and three-horse carts, together with the constant rumble of light carts, wagons and conveyances of every description. A cart with its dead load averaging 6,000 pounds, gives us conditions which are somewhat different to the ordinary buggy or double Germantown wagon, as in the case of the former we are nearing the crushing limit of our surface material. Of this class the paving should be of stone block surface, either

(1) Guidet or concreted foundation block pavement.
(2) Russ or patent section pavement.
(3) Belgian or granite block pavement.

What is most sought for in this class of paving is an even surface, with good foothold for horses, one thoroughly impervious to water and self-draining, and a pavement where stability will reduce the loss of original surface to the minimum. That is, one where the tractive force will be least with the greatest adaptability of foothold without permanent injury to the roadway.

(1) *The Guidet.*

The Guidet pavement consists of the ordinary granite block laid on its side on one inch of sand and on a bed of six inches of concrete, thoroughly rammed. As the durability of this roadway is evidently dependent on the concrete layer, it is more than evident that if perfection is reached in this alone, the sub-grade must take all the responsibility and be most carefully prepared, for the sinking of any part will make the part above worthless. The cost of this pavement is approximately as follows for one square yard:

26 blocks, trimmed edges, @ $11.00 per C.	$2.86
1 square yard of concrete @ $9.00 per c. yard	1.50
Excavation of roadway = 6″ deep	.10
Labor of laying and ramming	.50
Cost per yard complete	$4.96

This is exclusive of excavation over six inches, and allows a basis of two per cent. profit.

Russ Pavement.

(Pat. 1846.)

The Russ pavement is one which is designed more especially for the purpose of lifting out sections, to get at water or gas pipes, etc. It consists first in ramming granite chips about five inches in diameter into the roadbed and flushing them with top of same, flat side up. A concrete foundation is then laid in frames of sound wood, thicker at the bottom than at the top, by means of which the block of concrete, when hardened, may be lifted from its position, for access to the underground structures. On the top of this is then laid the block as before, the interstices well filled with sand or fine gravel. I know of only one instance where this pavement has been laid; and whether it was through inexperience or not I cannot say, yet it has now been entirely removed and pronounced a failure.

The cost of this pavement is as follows per square yard:

Spawls 5″ in diameter and 3″ deep, including placing by hand and thorough ramming	$ .28
1 square yard concrete, 6″ thick, made in hardwood frame, @ $15.00 per c. yard	2.50
1 square yard of sand, 1″ deep	.06
Sand for interstices	.05
30 blocks, 10″ x 4″, and 10″ deep, including laying, @ 11 cents	3.30
Cost per square yard, exclusive of excavation	$6.19

Belgian.

(*a*) with gravel joints.

(*b*) with pebble and pitch-cemented joints.

(*a*) This pavement, the most commonly used and the most economical of durable pavements, consists of Eastern granite blocks, about 10 x $3\frac{1}{2}$ x $7\frac{1}{2}$″ in size, laid on a gravel bed of 6 inches depth which has been thoroughly rolled and brought to a uniform grade, the interstices being filled with gravel, the blocks at once rammed with a 50 or 60-pound rammer, and the whole covered with a layer of fine, soft gravel.

(*b*) In this pavement the same bottom course of sharp gravel

is used, on which is placed one inch of clean, dry sand or very fine, clean gravel. On this the blocks are placed and the interstices filled with clean, hard quartz pebbles, and the whole thoroughly rammed as above. The loose pebbles are then swept off and the cracks filled with hot paving pitch, applied in liquid form, until they will receive no more, and the whole covered with an inch of clean, hard, sharp sand. The difference in the cost of these two pavements is only an additional cost of the pitch and the pebbles in the case of the latter, which would be about 12 cents per yard.

The cost per yard of the Belgian block pavement, with gravel joints, is as follows:

28 blocks @ 6½ cents	$1.82
Gravel	.10
Labor of laying, etc.	.36
Cost, exclusive of excavation, per yard complete	$2.28

These pavements are those best adapted for the heavy traffic of large cities for the reason I have already stated, and trust their approximate costs will be of interest and perhaps of use.

(*B*) Light Traffic Roads and Streets

Should be either

(1) Sheet asphaltum.
(2) Asphalt blocks.
(3) Brick.
(4) Macadam or Telford.
(5) Wooden.
(6) Gravel.

The much and deservedly abused cobble pavements, being considered unfit for city use, I will not touch on, except to say that they are a good feeder for the stone-breaker, and make excellent binder for the sheet asphaltum.

(1) *Sheet Asphaltum.*

Its advantages are, that it makes a noiseless, self-draining, impermeable, free-from-vapor roadway, with a great reduction of the force of traction on account of its smooth surface; yet, on the other hand, its disadvantages are great, being greatly affected

by change in temperature, affording little or no foothold for horses, being dusty in hot weather and slippery in wet weather; extremely hard in cold weather, while under the rays of an August sun it is soft enough to leave tracks and emit an odor extremely disagreeable; extremely pleasant to drive on, but correspondingly unpleasant to walk on when warmed by the sun. I have seen experimental tests by trotting horses on asphaltum, which have convinced me of its deleterious influences on horses. A horse was trotted at about seven miles an hour, over one mile of asphaltum, with the thermometer at 92 degrees in the sun. At the end of this mile I was hardly able to retain my hand on the base of the animal's hoof, so great was its temperature. I have seen horses trotted over Macadam, cobble, gravel and brick pavements under the same conditions, and the difference of temperature of a horse's foot noted with only a slight increase of temperature, hardly perceptible. The asphalt block has also this power of heat-absorption, but not to such an extent.

The method of construction consists of a base of broken $3\frac{1}{2}$-inch ring stone, laid $4\frac{1}{2}$ inches deep and rolled into place and thoroughly coated with hot paving cement, composed of coal-tar distillate. On this is placed the binder course, 2 inches thick, composed of $1\frac{1}{2}$ inches, heated and covered with coal-tar distillate, and spread evenly and rolled with a steam roller. The wearing surface is composed of a mixture of refined Trinidad, heavy petroleum, fine sand and powder of carbonate of lime, and is laid with a temperature of about 200 degrees F., and the whole swept with Portland cement and again rolled with a steam roller. The gutters are coated with vulcanite and smoothed off with hot irons, so as to make a thoroughly water-tight connection with the curb.

The necessity of making this pavement impermeable to water is evidenced from the fact that when hardened it will rot from water from below, and the roadbed, under the finest layer of stone, if washed by water, will produce the same results as mentioned above in block paving—namely, will cause the finished grade to settle and break. I am convinced that the advisability of sheet asphaltum is dependent upon the character of the climate. So different is our climate from that of the great cities of Rome,

Vienna, Bremen, Paris, London, Brussels and other foreign cities of street fame, that no comparison can be made between the durability of the same pavement laid here and across the water. The streets of Washington are not subjected to the heavy travel of cities of the first class, it not being a commercial center, and, moreover, the prices paid for asphaltum pavements there have cost $4.25 per yard instead of $2.30 and $2.60 here per yard. In the large cities like Philadelphia, New York, Boston, Chicago, etc., the same cause of complaint arises from asphalt pavements, that is, the rutting or wave-like holes forming, which are caused, not so much by an error of construction as by an actual working of the component parts of the asphaltum, caused by the heavy traffic at a time when the pavement, by the rays from the sun, has reached a certain degree of heat which makes it theoretically pliable or elastic.

Compare the asphalted street of Locust Street west of Fifteenth Street, Mt. Vernon Street west of Broad, and other light travel streets, with that of Broad Street or another one of heavy travel; the light travel streets are to-day perfect pavements, while North Broad Street is a disgrace.

The ignorance of municipal engineering is more apparent in this pavement than in any other. I have seen pavements of asphaltum where the whole street was asphalted, excepting the two feet adjoining the gutter on either side. This was laid with blocks. In other words, the place where impermeability to water should have been most sought for, and which, in the hands of skilled workmen, is carefully laid with Trinidad and ironed by hand, there is placed a pavement of such a character that access to the sub-grade by water is encouraged rather than guarded against. The settling of this asphaltum is apparent all along the gutter.

Lieutenant Gillmore, in his treaties on roads, etc., says of asphaltum paving: "A four-wheeled truck, weighing 3 tons, carrying a boiler weighing 21 tons, passed over a piece of asphalt pavement in Fifth Avenue near Twenty-fourth Street, New York, without leaving any mark." He, however, does not mention the thermometer on this day; but I think had it been 90 degrees F. it would have gone through, and had it been 30

degrees F. twice that load might have passed over without cracks. This author recommends also concrete foundation of beton in all cases, when it is the general opinion among engineers and road-builders that the broken-stone and coal-tar distillate is far preferable.

(2) *Asphalt Blocks.*

The manufacture of this block is far from perfected, the trouble being that the edges of the block chip off and constantly wear away until a round stone is left only a little better than a cobble-stone. Then, too, the price of the asphalt block is as high as, if not higher than, the granite block, and will last only one-quarter its time, so that until a more improved block is made for street travel it cannot become of general use.

(3) *Bricks.*

The vitrified brick pavement has had its boom, and sample pavements can be seen in many places.

This pavement is laid on Juniper Street, between Chestnut and Sansom Streets, in this city, and speaks for itself. It possesses the same defect as the asphalt block, breaking off and crumbling under travel, and soon becoming like a stone pavement.

In the *Engineering and Building Record*, a paper by Chas. Green, C.E., says: "A specimen piece of fire-brick pavement, put down in 1885, on Pearl Street, Cincinnati, has failed utterly." Certainly the Juniper Street pavement of this city has failed. There are many streets paved with brick in the northwestern section of Philadelphia, some of which are too new to judge as yet, while the older ones are in some cases as bad as Juniper Street. The cost of this pavement is from $1.40 to $1.65 per square yard.

(4) *Macadam and Telford.*

This pavement is unfit for municipal works, except in cases of suburban districts, or where a handsome drive or boulevard is desired, when police protection must be used to keep off heavy traffic. A glance at Twenty-second Street of this city will show the folly of such a useless expenditure of money.

(5) *Wooden.*

I regret most extremely that I have had no practical experience with wooden pavements; their advantages seem to be less wear and tear on tires and horses, less noise and smooth traction; their disadvantages, slipperiness in wet weather, and their power of absorption of animal excrement, which gives forth unhealthy odors when subjected to drying. The kinds of wood, methods of setting and modes of preparation for preservation, are so numerous that I will not enter into them here, but suffice it to say that from its perishable character and inability to stand heavy traffic, we do not desire to risk money in this changeable climate in a pavement we know has failed in so many cases to answer the demands thrust upon it.

(6) *Gravel.*

These roads of red gravel are suitable only for park purposes, and not municipal travel. Its advantages are smooth, hard, impermeable and less tractive surface at a low cost, capable of standing the ordinary light travel of carriages under the proper care of watering and general maintenance.

Gravel roads should be drained in all cases with stone or block gutter, as a gravel gutter will eat away and soon destroy the edge of the roadway.

I have purposely avoided discussion of Macadam and Telford roads, as I said above, as not coming under the class of street paving herein discussed. A golden opportunity awaits the man who invents the ideal city pavement—that is, one possessing the necessary essentials of smooth surface, capable of sufficient adhesion to afford tractive power a minimum, impermeable, clean, durable and capable of resisting very heavy dead loads, and, above all, economical. Certainly we are further from this now than were the ancient Romans.

DISCUSSION.

Mr. P. D. Borden, Jr.:—One question in connection with this subject I have never seen discussed, and that is, "What is the maximum grade on which it is safe to lay granite block paving?" We have gone as high as 5.66 per cent. on a street having much heavy teaming, and I think that is about as much as I care to go. I would like to know the opinion of the members on the subject.

Mr. Edward Samuel:—Referring to that part of the paper which gives as the dimensions of blocks, 10 x 3½ x 4½, laid on a 6-inch gravel bed, I would say that there is no such specification in use by any city in this part of the country. The New York specifications are, blocks not greater than 12 inches in length or less than 8 inches, ranging from 3½ inches to 4½ inches in width, and not less than 7 inches in depth and not exceeding 8 inches. The writer of the paper referred to says that the cost of this pavement is $2.28 per yard, and with pitch joints $2.40. I do not know where he gets his information from, but as these blocks are worth on the wharf $75.00 per thousand, and as the average is 25 to the square yard in actual working, the dead cost of the blocks would be $1.87½, to which must be added the cost of hauling, say 35 cts. per yard for an average haul, the cost of paviors' wages, amounting in plain work to 20 cts. a yard, and to this must be added the cost of gravel for bedding and gravel for facing, say 10 cts. per square yard of paving, making a net cost to the pavior of $2.52½ per square yard. It is fair to presume that the pavior is entitled to a profit in this class of work certainly not less than 10 per cent., which would make $2.77½; and this is where there is no grading, where the old bedding of the street can be used, and simply freshened with new bedding, and where all the conditions are favorable for the work. These figures are based upon actual knowledge of the cost in both Philadelphia and New York, taking Eastern granite as the basis and requiring the work to be first class. I do not compare it with the Belgian block paving generally laid in Philadelphia, which is with either Chester County blocks or Lambertville blocks, which, whilst an improvement on the cobble, are by no means the ideal Belgian block pavement that a city should have. All this type of pavements is practically

dear at any price where there is a heavy traffic, unless it is put upon a suitable foundation of concrete. This is especially the fact in Philadelphia, where the soil is a clay one, readily affected by frosts. To have good pavements in Philadelphia it is essential, first, that the necessary underground work should be done in the streets, so as to prevent their constant upheaval; secondly, that they be dug out to a sufficient depth to get the clay below the frost line; thirdly, that they be filled with concrete; and fourthly, that they be laid with a pavement with water-tight joints. The comments on the asphalt pavement in Broad Street and Locust Street are hardly fair. Attributing the disintegration of the Broad Street pavement to the heavy traffic, is wrong, because the same traffic, and a good deal more, passes around the asphalt pavement at the Public Buildings than it does on North Broad Street, and still the asphalt pavement around the Public Buildings is in comparatively perfect condition. The fact is that the North Broad Street pavement has no foundation, and any work in renewing the face there must necessarily be of the most temporary durability. The condition essential to a good pavement of any kind is a good foundation. Apparently in America people are unwilling to pay for this at once, and prefer bad pavements and annual payments to one good outlay and durability.

To-day the pavement offering the best possible conditions for city traffic is a concrete foundation of 18 inches in depth; overlying this a plank flooring of 2 inches, the flooring to be thoroughly covered with asphalt on both sides; on top of this flooring cedar blocks set on end, with $\frac{1}{2}$ inch divisional lines, and these divisions filled with beach pebbles and asphalt. I do not attempt to give the cost of this paving, and I have seen it laid in London, and I know from correspondents there that, after having tested all classes of stone and artificial pavements, nothing has been found which has given better results than this pavement. It gives a sure footing to the horses, a pavement easily kept clean, one which is comparatively noiseless, and one which can be renewed at any point rapidly and without interfering or the breaking up of other parts of the pavement which do not require renewal. It seems to me that this subject is of such very great importance at the present time as to suggest to the Club the creation of a special committee

to act in conjunction with the city authorities in formulating proper specifications for paving of the different types.

Mr. Rudolph Hering:—In matters connected with street paving we should look for information less to America and more to Europe, where engineers have had longer experience and have devoted more exhaustive study to the question, and where money has been more readily available for street improvements. In Philadelphia the question has been left mainly to Councilmen and others who were not educated engineers. That feature of our cities which perhaps most forcibly and unfavorably impresses the traveler, native or foreign, when arriving from Europe, is the great contrast between the two sides of the water in the matter of street paving. Among our own cities, Providence, R. I., can perhaps boast of the best paving, and Boston may come next.

Mr. Samuel, I think, hits the nail on the head when he insists that a good foundation is of prime importance. In fact the foundation is the real paving. Upon this is laid simply a veneering of blocks, asphalt, etc., to be periodically replaced when worn out. The foundation should form one solid block from curb to curb.

The great advantage which the European municipal engineer has over his American brother is that there the streets are not torn up at short intervals to lay or take up or repair sewers, gas or water pipes, etc., etc. All these are there placed under the sidewalks, and not under the roadway. Thus the streets are generally left intact. Here it seems scarcely worth while to place proper foundations under the paving, because the engineer may be morally certain that as soon as laid they will have to be taken up for the purposes referred to. In Europe, when street extensions are contemplated, plans are made in advance for water and gas pipes, sewers, etc., and these are first put in place, often long in advance of actual requirements, and the paving is then laid down and allowed to remain. This is one of the secrets of the excellent character of street surface in Europe.

I must disagree with the author in his remarks upon the crowning of the surface. The object of crowning is to facilitate the flowing off of the surface water; hence the steepness of the

crowning should vary with the roughness and porosity of the material, whereas the author has given greater crowning for stone, etc., than for more absorbent materials.

The crowning of asphaltum pavement may be reduced from the figures given if it be laid on good foundations.

As the author claims, the best paving is the stone block, but I have never yet seen an American block pavement to equal those laid in Europe. The reason is that the blocks here are much less accurately dressed. In Europe, a block varying more than a quarter of an inch in its dimensions at the joint is generally rejected. In Liverpool, stones intended to be laid next to tramway rail joints are rejected if they vary more than one-eighth of an inch. The advantage of narrow joints between the stones is, of course, that the hammering by passing wheels is greatly lessened, and the wear thus reduced. The blocks in America are roughly dressed, leaving wide spaces between them, and the consequence is that under the blows of passing wheels, the edges soon become rounded, and the pavement comes to resemble a cobble pavement.

Another trouble with our stone pavements is that the blocks very often are too soft, so that they wear readily.

I must also disagree with the writer as to the propriety of covering a Belgian-block stone pavement with sand after it is rammed and pitched. This practice seems to be simply a relic of cobblestone practice. At best, the sand soon washes away into the sewers. In New York I have seen pavements on concrete foundations and the joints filled with sand and pitch and afterward covered with this useless gravel. This practice does not obtain in Europe.

The pitch is used, not merely to keep out water, which, in fact, it does not do (the pitch disintegrates in a few years, especially where the foundation is soft); its object is simply to fill the spaces between the pebbles in the interstices and to keep out street dirt; it is not water-tight.

The author, it seems to me, is unjustly severe upon the asphalt pavement. As to the American article, his strictures are often justified, but in many European cities the asphalt is giving excellent satisfaction. Much depends upon the kind of asphalt

used and the manner of laying it. There are two principal kinds of asphalt paving; in one the rock asphalt of Seyssel, Val de Travers, etc., is used, and in the other the Trinidad asphalt, mixed with sand, etc. Rock asphalt is expensive and has been unsuccessful here, and the Trinidad article is generally used in its place. In Europe, where the asphalt pavements are kept scrupulously clean, the rock asphalt gives excellent results, and is not much more slippery than granite.

A clean asphalt pavement is not slippery in wet weather.

The author complains that asphalt pavements are "dusty in hot weather," but what pavements are not dusty in hot weather unless the dirt is removed from them?

As to the fact that changes in temperature disintegrate such pavements, it must be said that they do not affect the rock asphalt pavements of London, Paris and Berlin as they do the Trinidad pavements here. Cheapside, in London, was paved with rock asphalt until a short time ago, and sustained, perhaps, the heaviest traffic in the world. It was down for more than eleven years, and gave excellent satisfaction.

Mr. Bullock:—I have been told that sand was sprinkled on the asphalt paving on Cheapside. Can Mr. Hering tell us whether this was the case?

Mr. R. Hering:—Yes. Sand is strewn upon the asphalt, and upon the wood pavements also, where the grade exceeds 2 feet in 100, but not on level stretches. Sand is not used in Berlin except between tramway rails.

It certainly cannot be said, as the writer claims, that asphalt is useless except for light traffic. The example of Cheapside is sufficient to disprove that.

The wood pavements, which our author cursorily dismisses as quite worthless, are the ones that have achieved the greatest popularity in London and Paris within the last ten years. Wood paving is there considered preferable to all others. In our own Western cities wood has given excellent results. With wooden pavements it is of the first importance that the wood should not be of a perishable character. In Europe the wooden blocks are creosoted before laying, and great care is given to the foundations. Furthermore, a good system of repair is maintained. The pave-

ment is carefully inspected at short intervals, and wherever a defective block is found it is at once removed, and a perfect one of the proper size is put in its place. Under such a system the holes which disgrace our American wooden pavements do not occur.

Mr. Bullock :—Do they use cedar in Europe?

Mr. Hering :—Norway pine, mostly, I think.

Mr. Bullock :—I understand that American deal is also used.

Mr. Hering :—Cedar is successfully used in Detroit and Chicago. In Texas I saw pavements of Osage orange wood that had been down for seven years and showed no rot. They are very economical there, where the wood grows, and seemed to be the best pavements for their purposes.

Brick is sometimes successful and sometimes not. Here, too, it is most important to use the right kind of material. Wheeling fire-brick, which is so largely used, is not the best. The best, I believe, is from Galensburg, Illinois. It is very hard, like the Staffordshire brick, and tough.

(Mr. Hering here exhibited kodak photographs, taken in Europe, showing Belgian blocks piled up for use. The photographs showed admirably the careful dressing which the stones received, a pile of such blocks resembling a wall of ashlar.)

Mr. James Christie :—Mr. Borden inquired as to the limiting grade to be used with stone block pavements, stating that they had used as high as five or six per cent. This pavement is in constant use in this city on grades of ten to fifteen per cent.

Mr. Hering :—I have seen cases where Belgian blocks were laid on grades of about 30 feet per 100, but they were little used and were overgrown with grass. In Duluth 10 per cent. is considered a proper maximum, but some of the grades are much steeper. On some that reached 20 per cent. flat cobbles were used, set on end, and give an excellent footing for horses.

Mr. Bullock :—This question of paving is one of the most important which the citizen has to consider. It is, in fact, as vital in its interest for him as that of his milk and bread supply. We have been trying for years to improve the character of the pavements in Philadelphia, and the obstacle which has met us at every turn is the cry of "no funds." The officials are all right:

we are not ignorant as to what is wanted or as to how to do it, nor are we lacking in desire to do it, but we cannot do it without money.

Under our municipal regulations, the cost of paving a new street, in the first place, devolves upon the property-holder. He, of course, wants it done as cheaply as possible. After we have paved our five or six hundred miles with cobbles, the property-holder comes forward and wants the streets repaved with improved material out of the general fund. When I came into the department, my proposition was to take up the cobbles, break them in a stone-crusher, and use them in concrete foundations, placing Belgian blocks on top; but it was immediately objected that this would cost from $3.50 to $4 per square yard, and we had to content ourselves with a $2.50 paving on gravel. Now, gravel is not the best foundation for a pavement.

The question is, can we educate the people up to the point of paying for the proper thing?

Mr. Samuel is right, so is Mr. Hering, in insisting upon the prime necessity of a first-class foundation; but how are we going to have this under our present arrangements? An ordinance is passed to repave a street. We go around and ask the bureaus what there is to be done. We are told that sewers are needed here, a new water-main there, and a new gas-main in a third place; but the order says, "Pave *this year*." Now, everybody knows that we cannot put in those sewers and mains and have the ground settle, and pave properly within a year. We have been trying to work around to the European practice of getting all the underground work done first, before we lay our pavements, so that a first-class pavement need not be taken up as soon as laid for every trifling leak in a water-main or break in a sewer. There is no use talking about first-class pavements on poor foundations.

I must take exception to the author's remarks upon the crowning of the cross-section. I have in my hand copies of our specifications in which it is provided that with Belgian block the grade shall not exceed one-quarter inch to the foot, and I believe this is all that is required. The railroad companies, if we do not watch them, will put their tracks up higher than this in order

to facilitate the removal of snow. In repaving during recent years we have done away with all such steep crowning, but we have scarcely more than made an impression upon the vast amount of work to be done in this line. We have repaved some 10 or 12 miles out of the 300 occupied by the railway companies.

The careful maintenance which Mr. Hering described as in vogue in Europe is, of course, an excellent thing for the streets, but we cannot afford it here.

The author is wrong in his explanation of the trouble on North Broad Street. That pavement was laid in 1882 and 1883 under a five-year guarantee, and the city has paid nothing until now. The author tells us that the foundation was defective, but we have recently taken up a couple of hundred yards of it in the neighborhood of Norris Street, and I should like to have any of you gentlemen come up there to-morrow and examine the character of the concrete foundation. You will find it in perfect condition. The trouble on North Broad Street occurs from two causes: in the first place, the coating of asphaltum was too thick; it should not exceed 2 or $2\frac{1}{2}$ inches, otherwise it is apt to "shove" in hot weather. In the second place, there was no bond between the coating of Trinidad asphaltum and the concrete base, and the consequence was that the coating slipped on its foundation. Now, in relaying this pavement, we are using the vulcanite base and binder, which is simply a concrete made of small stones with No. 4 coal-tar. There is no cement in it. This serves as a binder between the top coating and the foundation below. If you want to take up the surface coating laid on this binder, you will find that the top of the foundation comes up with it. There is no slipping when it is used. Last fall Dr. Filbert repaired some holes on North Broad Street, using this base and binder, and it was afterward found impossible to detach the top coating from the foundation.

The asphaltum pavement on Thirty-ninth Street has this base and binder, and forms a first-class surface, equal to any in the world.

The author contrasts North Broad Street with Locust and Mt. Vernon Streets, and believes the reason for the difference in their behavior to be that Locust and Mt. Vernon Streets sustain

only light traffic, while Broad Street gets the 'busses and other heavy traffic. The true reason is, that Locust and Mt. Vernon Streets, being east and west streets and quite narrow, are to a great extent shaded from the sun; whereas Broad Street, being a wide north and south street, is exposed to the sun's rays during the hottest part of the day.

The author remarks that asphalt will not wear under heavy traffic. The difficulty is that *as soon as an asphalt street is down the traffic all goes there*, thus the asphalt pavement falls a victim to its own excellence.

I have heard a great deal about that celebrated Appian Way and the other Roman roads. It is no wonder they stood, for the Romans used wooden wheels twelve inches on the face.

Years ago 1,500 pounds were considered a load for one horse on cobbles with wheels 3 inches on the tread. Farmers came in with 6-inch wheels. Now 8,000 pounds are a common load for a pair of horses (or, say 3,500 pounds net per horse), with $2\frac{1}{2}$ to 3-inch wheels. Our present roads won't bear this traffic.

It would be a most desirable thing if all our streets could be at once relaid with first-class pavements; but have you stopped to consider what this will *cost?* Say we have 500 miles of streets to improve. That would cost for the mere repairs to the streets some $21,000,000. You must add to this the necessary repairs to sewers, etc., which would bring it up to $50,000,000.

By all means put the sewers, water and gas-pipe connections under the footways, and let there be a small sewer under each footway rather than one large one under the street, and make your connections at the ends of the blocks. During my first year in the Highway Department, in driving down town I noticed that some Belgian pavement, only recently laid, had been torn up. On returning to the department I inquired why this was done, and was told that it was an order to lay a gas main. Now, why could that not have been done under the footway?

The character of our work is improving. The Belgian blocks we are using are equal to those of other American towns; in fact we had a letter recently from Providence asking how we succeeded in getting an average variation of only one-half an inch

in our joints. Our blocks come from Cape Ann, Lambertville, Souderton, French Creek, etc.

The European blocks are cut by hand. Some years ago, a gentleman, on Sixteenth Street below Sansom, laid a pavement in front of his residence where the stones alone cost him $2.75 per square yard. They were 2½ inches square and 6 inches deep, and set in a cement concrete base. Of course that pavement is good, and we will put it down all over the city if you will furnish us the money. The South Street bridge pavement is also laid in cement.

The Secretary:—When the asphalt pavement was laid around the City Hall, the pavement was taken up in order to put down the sewers, gas pipes, etc.

Mr. Bullock:—The pavement around the City Hall is the best possible. A ditch cut in asphalt can be very easily repaired. The ditches ought to be thoroughly rammed, and then there would be no difficulty. The trouble is that this work is done by irresponsible plumbers, and the department cannot force them to do it right. We have to pave over the holes they leave.

Mr. W. W. Thayer. Reply to Discussion, read November 21st, 1891.—In reply to Mr. Philip D. Borden's question of heaviest grade permissible for Belgian-block paving that can be laid, I would say that this pavement, affording as it does a good foothold for horses, can be laid on any grade which is necessary in municipal engineering. There are grades of nearly 13 per cent. on some streets in Philadelphia laid in Belgian block.

Replying to Mr. Samuel:—Mr. Samuel says, "The author of the paper on street paving refers to blocks 10″ x 3½″ x 4½″ laid on a 6-inch gravel bed."

This is a typewriter's error, and should read 10″ x 3½″ x 7½″.

I reiterate my statement that Belgian-block paving can be laid for $2.28 at a low profit.

Permit me to estimate on a different basis:

1 sq. yd. of Belgian blocks measured in pavement	$1 70
Gravel	10
Labor of laying	36
Hauling	12
	$2 28

To further substantiate my quotation of the price of paving, let me give you the contract figures for a district of Philadelphia. The bids for block paving in the 11th, 12th, 13th, 14th, 15th, 16th and 17th Wards gave for this year a mean price of $2.30 per yard for block paving, some bids being as low as $2.19.

I do not for a moment say that there was any profit in these prices, but the work was done at that figure, and men do not work for nothing. I should greatly like to hear an estimate of the cost of the pavement that Mr. Samuel advocates so strongly.

Mr. Samuel, I think, is mistaken in saying that the trouble with North Broad Street is that it has no foundation. It has a foundation of concrete, as Mr. Bullock has stated.

Mr. Samuel can readily see how far from a "comparatively unaffected pavement" that around the City Hall is by walking over the ground on a wet day, when we can see pools of water, in some instances three-fourths of an inch deep, laying near the very crown, or still further by counting the patches which are very evident on the surface.

Replying to Mr. Hering, who says:—"I must disagree with the writer as to the propriety of covering a Belgian-block pavement with sand after it is rammed and pitched," etc.—my theory of this is that the hot pitch, coming in contact with the cold stones, is chilled and does not thoroughly fill up the interstices, and the sand, applied as I have mentioned, lends stability to the mass by filling in the small interstices between the pitch and blocks. What is washed away by water is evidently not needed in this operation.

I regret that I did not make the title of my paper read, "Street Paving as Adapted to American Cities," for I see Mr. Hering has taken us into other climates across the water; and, as I stated emphatically in my paper, the differences in climate are greatly to be observed in the construction of pavements. I most certainly did not intend to "dismiss as worthless" the wooden pavement, as Mr. Hering evidently construed my paper, but, from the apologetic way that my article on wooden pavements reads, intended rather to pass this species of pavement, through my lack of practical experience in it and my lack of knowledge as to its capability for permeability.

Replying to Mr. Bullock:—Mr. Bullock says, "I must take exception to the author's remarks upon the crowning of the cross-section." In repaving in recent years, we have done away with all such steep crowning.

Three inches in 40 feet are certainly not a steep crown for asphalt, being only 1-16 of an inch to 1 foot. Asphalt last year was laid in this city with a crown of 1 inch in 30 feet, and the specifications of this city call for a crown of 1 foot in 50 feet. I, therefore, cannot see why Mr. Bullock has taken exception to my table of falls of crowns for roadways.

Mr. Bullock then states:—"The author remarks that asphalt will not last under heavy traffic. The difficulty is that as soon as an asphalt pavement street is down the traffic all goes there. Thus the asphalt falls a victim to its own excellence."

I think the remark, coming as it does from a man so thoroughly conversant with the streets of large cities, is a strong point toward the classification of such pavements among the light-traffic ones.

VIII.

STREET PAVING.

By Walter Brinton, Active Member of the Club.

Read November 21, 1891.

It shall be the object of this paper to mention as briefly as possible some of the evils of the present system of street paving in Philadelphia.

The opinions advanced are based on some experience in the subject-matter in the outlining wards, where a large amount of new work is now in progress.

Of late years there has been much speculation, much interesting and valuable controversy, as to the proper material to be used in road construction. The condensed opinion of a vast amount of this published matter would indicate that we have not yet obtained an entirely satisfactory substance for street surfacing. The question as to whether we are doing the very best we can with the material we are using is one that should not be lost sight of in the establishment of our new Philadelphia.

Stone, whether used as found in the quarry or in composition with other material, has always proved itself to be the most reliable article for paving. And there should be no more reason why this material, which nature has so abundantly afforded, cannot be made subservient to our wants and comforts in the matter of good roadways any more than in its application to magnificent railroad bridges or permanent buildings.

Within a reasonable limit, stone is indestructible; its nature is such that an accurate judgment of its quality and strength may be determined from external appearances. A moment's glance reveals the fact whether it is hard or soft. There can be no excuse for using poor stone in street paving, and, generally speaking, our streets have a good quality of stone. The complaint is not from this source. The streets of Philadelphia are in bad repute from the method of workmanship, and not from poor material.

The character of paving differs widely with the nature of the improvements along the line of travel. A well-constructed Tel-

ford road meets satisfactorily all the requirements of what we may term pleasure roads. Vitrified brick, composition block and sheet asphaltum have given good results on streets where the travel is light and not confined to narrow limits. Granite block is in most universal use, and the method of street construction with this material is the main object for discussion in this paper.

A large proportion of the paving block now in use is from the Lambertville or French Creek quarries.

It is a good, substantial granite, and unless the line of travel is very much contracted, or very heavy, there is no appreciable wearing out of stone.

The stone is usually dressed at the quarry in sizes of about 7 x 4 x 10 inches, and is laid in 6 inches or 8 inches foundation of gravel and sand, rammed and the joints filled with pitch or cement, the cost ranging from $2 to $3 per square yard. A newly finished square of block paving is generally a thing of beauty, but by no means a joy forever. A heavy dash of rain, a little moisture working through the foundation, or the passage of a dray gives rise to the thought, that either the specifications have not been faithfully followed or that the specifications themselves are at fault.

The two essential requirements for good paving are that the foundation should be solid, and that the finished surface should be water-tight. A good foundation with a loosely laid surface is quite as objectionable as a good surface with a spongy bed.

All specifications for street paving state that the foundation shall be well rolled or rammed before the stones are set in place, and that the stones themselves shall be rammed three times with 55-pound rammers. To thoroughly ram a street foundation from curb to curb for an entire square is hard work, and is generally very imperfectly done. The sand in common use, known as Jersey sand or gravel, cannot be rammed until it is firm and binding. It might be rolled to better advantage, but steam rollers are expensive, and, at present prices, few contractors can afford to use them.

The most persistent enemy to the maintenance of paving is water. It may enter from the sidewalk, gutters, through open joints in the curb, from the street gutter, or from the joints between the blocks.

If a street is occupied by street-car rails, we will notice the stones near the rail losing their original position and sinking 3 or 4 inches below the street surface, indicating that water has followed the rail until it has found an outlet, and gradually permeates and loosens the foundation-bed.

If a street has a moderately steep grade longitudinally there will be very little moisture to enter between the stones; with properly constructed gutters, the grade transversely could be much lighter than at present, the gradient now in use being 2′ 6″ per 100′ from the gutter to the middle of the street.

The new experiment of mixing one part sand with one part Portland cement, and filling the joints for a space of 4 feet from the curb, is a questionable one. I have noticed that under heavy traffic the cement cracks and separates from the stone.

The pitch-joint paving, while it is open to the same criticism, is more tenacious, and tends to keep the joint well filled. It is not the intention to convey the idea that all paving contracts are poorly executed, but a day's journey over some streets that have been improved within the last five years will furnish strong proof that they are not as good as they should be. It is one thing to detect the fault, but quite another to suggest a remedy.

A good article costs a good price, and economy in first cost is not a safe rule in street paving. But where is the money to come from, to construct more substantial roads?

The tax rate stands solidly at $1.85, and there is certainly no relief from this source at present. It costs the property-owner about seven dollars per linear foot to obtain all the necessary improvements for his house, and he is not willing to pay more. Two methods may be suggested. From 1885 to 1891, inclusive, one million dollars has been appropriated to the Bureau of Highways for repairs to streets that have been paved. A small percentage of this amount is used in repairing necessary breaks caused by the introduction of gas, water, etc. The balance is used to repair worn-out cartways. Many streets are repaired year after year and are always in bad condition.

Now, we should either repair a street by removing the old surface from square to square and constructing a new improved pavement, or transfer, say, 10 per cent. of the annual appropria-

tion, amounting to $16,000, and construct a pavement costing $3.50 to $4.50 per square yard. When a sewer is built the abutting property is taxed $1.50 per linear foot, without regard to size, shape or material of sewer, and we are building good sewers.

I believe the assertion is a safe one, that if the city would pay the extra dollar per square yard of paving, it would not be many years before the annual expenditure of $160,000 for repairs would be largely diminished. The two most essential improvements would be to dress the stone to a neat surface, to insure close joints, and to thoroughly roll the foundation-bed. There is also an urgent need to improve the inspection on a large amount of new work.

From some little investigation and comparison, the following general facts may be submitted relative to block paving. A street with a grade of 2 feet per 100 feet will be found in better condition than one with only 6 inches per 100 feet. It is not always possible to drain a territory with a 2 or even 1 per cent. grade; but by giving the gutter a stronger gradient than the street, and draining the surface water into drop inlets at the depressions, this difficulty may be largely overcome. A street with a low transverse grade will be found in better condition than a street with a high crown.

The reason for this seems to lie in the fact that the travel on high-crowned streets is confined to the middle of the street in preference to the sloping sides, and the continued line of travel on the summit soon destroys the shape of the roadways. A street with the gutters three or four inches below the surface of the paving will be found in better condition than one where the gutter has been constructed with the general slope of the paving. By this method the surface drainage is confined solely to the gutter, and there will be fewer leaks. Streets are much better preserved in localities where dwellings are all underdrained, because the only water in this case that reaches the street is from the natural rainfall.

It is the continual flow of water that comes overland from the rear of dwellings that endangers the sidewalk, the curbing, and finally the street paving itself. Thoroughfares occupied by street-car lines will always be found inferior to those which are not.

The track repairs tend to gradually elevate the crown of the street, until the sloping sides from the rail to the curb become almost dangerous in many cases ; and the continual removal of stone and disturbance of foundation have a deleterious effect upon the surrounding paving. This is a difficulty that is hard to overcome.

It may be that the recent decisions of the Supreme Court, compelling street-railway companies to lay improved pavements on streets occupied by their tracks, will develop some new methods either in track construction or for the paving itself.

Streets built on newly filled ground, even if the gravel foundation is very compact, do not retain their shape as well as do those streets which are built in excavation. This has been a very serious error in certain sections of the city.

A street that has required a large amount of filling to bring it to grade should not be paved within a year. Our public highways and the method of their construction constitute a department in the city government that is second to none in its importance. We are building good sewers and bridges, have reasonably good gas and water, but the cavils over our highways would suggest that they might be better. The question, "With what shall we pave our streets?" is as important as that of "How shall the work be done?" Poor work with good material can never be condoned. And it is highly important that the engineering profession become interested, and endeavor by some means to aid the taxpayer in securing better results for the outlay of his money. If we cannot improve on the old methods, if we have no better street paving to offer, can we not control its construction by intelligent inspection, and maintain it by judicial legislation?

IX.

SMOKE ABATEMENT IN CITIES.

By George R. Ide, Active Member of the Club.

Read December 5, 1891.

In burning bituminous coal in an ordinary boiler furnace without taking especial precaution, a cloud of yellow-brown vapors or gases may be observed to pass out from the chimney with every fresh charge of fuel. This cloud is composed of the unburnt gases distilled from the fresh fuel in excess of the capacity of the furnace for utilization in producing heat, and represents the loss or waste of so much fuel which, under proper conditions, might have been saved. When the heat of the furnace arises to a sufficiently high temperature, these gases become ignited and partially consumed. The hydrogen of the hydro-carbons unites with oxygen of the air-supply, which is ordinarily passed under the grate and through the furnace doors to produce water-vapor; the carbon of the decomposed hydro-carbons becomes partially converted into carbonic acid while heat is being generated, the unconsumed carbon being precipitated in finely divided particles and carried off in black clouds from the chimney by the invisible water-vapor of combustion as a vehicle. This black cloud comprises the smoke which we are now to consider. It is particularly objectionable by reason of the disagreeable smutty appearance which it gives to everything in the neighborhood of the chimney; by reason of the unpleasant condition which it renders to the atmosphere which we are compelled to breathe into our lungs, and by reason of the injurious effects produced upon vegetation. Of these objections the first is the most noticeable, and consequently the most regarded in general. The amount of fuel wasted by the formation of this sooty smoke, however, is not so great as one would be apt to infer from appearances. It has been estimated by the Smoke Abatement Committee, London, 1882, to be not greater than one per cent.

The systems for supplying fuel to the furnace by hand are three, viz.: (1) the spreading system, in which the coal is

thrown at random evenly over the entire surface of the fire. (2) The coking system, in which the fresh fuel is piled up on a coking table or dead space in the furnace in front of the grate, so that the gases of distillation will pass to the rear over a bed of glowing coals to be ignited and burnt. When another charge is about to be supplied the pile of coked fuel is pushed off from the coking table toward the rear, after which fresh fuel is again placed on the table to be coked as before. (3) The alternate side-firing, a modification of the second, in which the fuel is spread evenly upon one side of the furnace, beginning at the rear and working toward the front, and leaving the other side bright with live coals to ignite and burn the distilled gases arising from the fresh fuel, and then, after these gases have been burned off and the last-supplied fuel is in a glowing condition, another charge of fuel is thrown upon the other side, leaving the side first charged covered with glowing coals to burn off the gases as before.

By the exercise of a great deal of care in hand-firing and applying some judgment in opening and closing of the furnace doors, much smoke may be avoided without the aid of any fixed mechanical contrivance. To avoid the formation of smoke in such circumstances, the alternate side system of firing should be used; the fuel should be thrown on to the fire in small quantities, and a large supply of air should be permitted to pass through the doors until the yellow and brown vapors are burnt off, when the air-supply should be gradually checked. Ordinarily, however, the fireman cannot devote all of his time to continuously furnishing the requisite small quantities of fuel and attending to the draft. He will rather throw on large quantities at intervals, which will cause the fire to be cooled below the temperature necessary to ignite the gases, and until a sufficient temperature is again attained the fuel will give off great volumes of smoke together with considerable loss of heat which might have been obtained from the unburnt gases and carbon particles passed off at the chimney.

A simple mechanical contrivance for promoting combustion consists in forming a table or dead space at the front of the grate, upon which the fresh fuel may be piled and coked, and from

which it may afterward be pushed to the rear. In an experiment, made as early as 1869, at Wigan, near Manchester, for comparing the spreading system of firing with the coking system, black smoke lasted 4.2 minutes by the spreading, and none appeared by the coking system, and very light smoke lasted 20.8 minutes by spreading, and but 3.2 minutes by coking, showing the latter system of firing to be vastly superior to the spreading in abating the smoke nuisance. By the introduction of a hanging bridge behind the fire wall, to deflect and more thoroughly intermingle the vapors in the combustion chamber, the duration of very light smoke was further reduced eighty per cent.

The coking system, with the introduction of a current of air above and beyond the coking chute or hopper, is quite old, and is disclosed in the English patent to J. and J. Roberton, dated August 13, 1800. This system failed in practice because it required more labor and attention than the firemen could be induced to bestow.

Since the date of the Roberton patent a vast number of inventions of mechanical contrivances have been made, with a view to the abatement of the smoke nuisance and the more economical consumption of fuel. In the United States alone there have been probably 1,000 patents granted upon such contrivances. These inventions cover improved means for causing the distilled gases and the air to become more thoroughly mixed; for supplying air to the furnace at a number of places around the grate; for heating the air-supply before introducing it among the gases; for forcing the air, either at the normal temperature or heated, over, or into, or under the fuel, by fans or steam-jet blowers; for automatically regulating the draft after supplying fresh fuel; for re-heating the unconsumed gases in a separate and enlarged combustion chamber supplied with heated air; for dividing the furnace longitudinally by a wall to better facilitate alternate side firing; for raining fine fuel in a spray over the glowing coals; and for washing the smoke, before it makes its exist from the chimney, in order to remove the carbon particles.

All or most of these contrivances are old in principle, but embodied in more preferable forms, and most of them are, in

considerable degree, successful in preventing the production of smoke in objectionable quantities. Why, then, are these contrivances not more universally adopted? Among some reasons why they have not been more extensively used is the first cost of inserting them in new establishments, and the still greater expense of tearing out the old and building in the new setting in the older establishments. Many proprietors of smaller establishments do not realize the continual pecuniary losses which they are suffering in not getting the best results from their fuel by the use of improved appliances, nor do they give any consideration to the smoke problem so long as it only inconveniences their neighbors and not themselves. Another reason why the nuisance is not abated arises from the fact that there is, in many towns and cities, no law relating to the prevention of smoke, or, if there is any, it is not enforced from fear that the manufacturing industries may be driven to localities where the authorities are less meddlesome. It is only occasionally in this country that the attention of the authorities is called to this nuisance, as was done not long since concerning the application of the Washington and Georgetown Street Railway Company for a permit to build their traction power house near the heart of the business portion of the city of Washington. A resident objected to the location of the site chosen on account of the smoke which was liable to be formed. The District Commissioners ordered an investigation at the power house of the Seventh Street line, and found that by the use of mechanical stokers the coal was fed to the furnaces so uniformly, and the combustion was so thorough, that little, if any, smoke appeared at the top of the chimney, and what little did appear did not last for any great length of time. The permit was given and the house is now being built upon the site first selected, all opposition having been withdrawn after the report of the investigation. There are, however, numerous chimneys in the heart of the city of Washington from which clouds of black smoke are daily emitted. But no attention appears to have been paid to these, presumably because each one of the offenders is so small in itself.

From the Official Report of the Smoke Abatement Committee, in 1882, it is quite evident that by use of improved designs of

Fig 1.

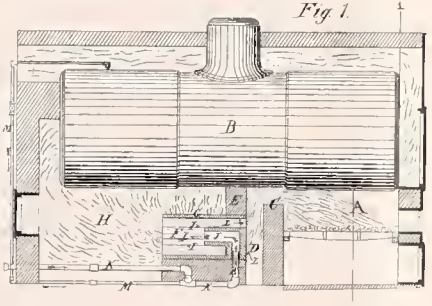


Fig 2.

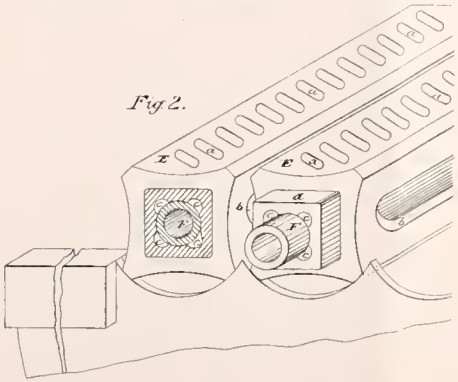


Fig 3.

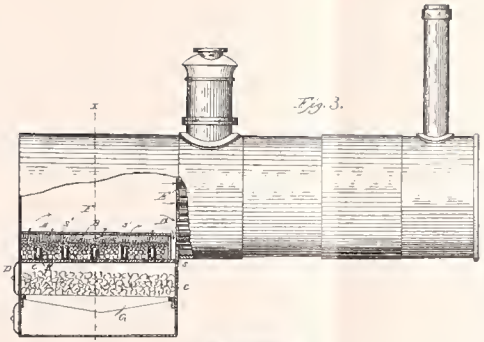


Fig 4.

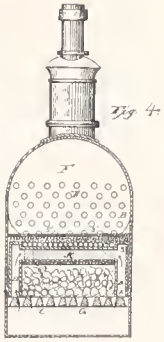
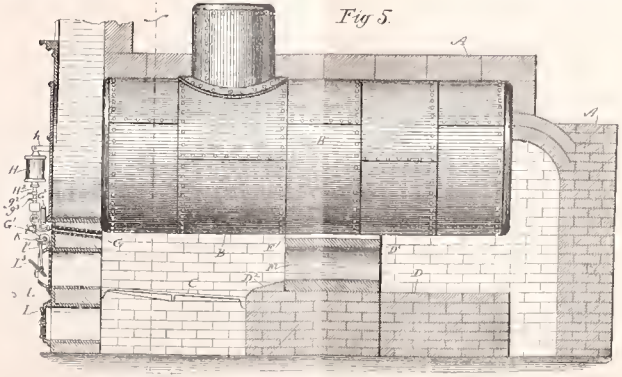


Fig 5.



furnaces and methods of operating them, the smoke nuisance may be reduced to almost, if not quite, a dream of the past. Since the date of the report above referred to, probably one-half of the patents granted upon furnace construction have been issued in this country, and a few of the later ones will now be referred to, to show the lines upon which inventors have been working and to bring out more fully the results which it is desirable to attain. No opinion will be expressed as to the merits of the patents referred to.

R. B. Ayres, in 1886, received a patent for a furnace (Fig. 1*) in which a retort, *F*, is located in a flue, *G*, in a wall, *E*, placed back of the fire-wall *C*, and leading to a large combustion chamber, *H*, in the rear. A centrally located air-supply pipe, *J*, leading from outside the furnace, is extended part way through the flue and is directed toward the rear, so that the distilled gases may be carried through the flue and intermingled in their passage therethrough with the rearwardly directed jet from the air-supply pipe to produce a violent combustion in the combustion chamber at the exit of the flue.

Ashcroft, in 1886 (Fig. 2), endeavored to secure complete combustion by means of pipes, *F*, passed longitudinally through longitudinally and transversely perforated grate bars *E*. The tubes lead from outer air to a chamber in the bridge-wall having openings communicating with the combustion chamber in the rear If desirable, the air may be forced through the pipes by steam-jet blasts. On its passage through the pipes the air is heated before its delivery to the combustion chamber. The transverse openings *a* in the grate bars are for supplying air to the under side of the fuel.

Player, in the present year, received a patent for a device for automatically opening and closing the valve of a steam-jet blower in a locomotive simultaneously with the opening and closing of the throttle valve, for the purpose of burning the smoke particles as the train is coming into the station, or is at a standstill. No means, however, is shown for shutting off the blowers when it is desired to bank the fire.

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* The figures are reproduced from those in the patent specifications.

Edgar, in 1889, received a patent for a method of more thoroughly mixing the air-supply and the distilled gases (Figs. 3 and 4). An incombustible box, having air-ducts leading thereto from below the grate, is filled with fire-clay balls or fragments of other refractory materials. The box is placed over the fire, so that the gases are obliged to pass through the perforations therein and into the interstices between the clay balls, which are heated to incandescence. The balls vary in size, the larger ones being placed at the bottom of the box, or nearest to the grate. The theory of the invention is that the gases and the air will be thoroughly commingled without danger of explosion, and that total combustion will follow; and, furthermore, the mass of incandescent clay balls will insure a uniform temperature.

Bowe, in 1887, obtained a patent for a furnace provided with a number of features (Fig. 5). Air is supplied above the fuel by automatically-controlled steam jets *G*, each of which is placed in the front of the furnace over the doors, and is directed toward a flue, *F*, in the fire-wall. The fire-wall is so built as to have a uniform width of space, *E*, around the boiler, to insure uniform heating, and is extended back to the rear of the boilers, nearly reaching to the bottom of the flues, so that the combustion chamber is not abruptly enlarged in rear of the flues, thereby tending to avert eddies, in the combustion chamber, which cause unequal expansion of the boiler plates. The dampers L_3 in the furnace doors are automatically controlled by the device which controls the steam jets. The draft-controlling device comprises an open-topped dash-pot, *H*, or cylinder filled with oil or water and having fitted therein a weighted piston, the latter having a downwardly-opening valve and a hollow piston-rod. The piston-rod has a small adjustable opening leading to the upper face of the piston. The lower end of the piston-rod is connected with a lever on a horizontal rock-shaft from which cam-arms extend to act upon plungers connected with the dampers. Guide-arms g_2 g_3 on the piston-rod engage an arm on the valve for admitting steam to the steam-jet blowers. Bevel gears on the horizontal shaft engage with gears connected by suitable clutches to the furnace-door hinges, so that when the doors are opened the shaft is rocked and the piston raised, the steam-valve and dampers being simultaneously opened. After the doors are closed the

weighted piston falls slowly, the oil or water being permitted to pass through the opening in the piston-rod to the top of the piston. As the piston falls the steam-valve and dampers are gradually closed, as less supply of air is required in the furnace

Another patent granted to Edgar, in 1891 (Fig 6), showed two walls, *W W*^{1}, of fire-brick, or other suitable material, built in rear of the flues of a tubular boiler, with the wall adjacent to the flues perforated near its periphery at *a*, while the wall adjacent to the smoke-stack or chimney has a central perforation, *a*^{1}. The inventor's theory is that the first or inclosed wall, being protected from cooling drafts, will be heated to incandescence, and that the carbon particles which impinge thereagainst will be ignited and consumed before they reach the smoke-stack.

Ayer, in 1891, received a patent for a furnace (Fig. 7) having a water-grate, *F*, supported by and having connection with a water-leg, *E*, in the rear of the furnace. Circulation is insured in the water-leg by pipes, *H*, leading from the lower end thereof to the water-wall *G* at the front. The fuel chamber is above the grate, and the gases are forced downward through the grate to the combustion chamber below, whence the heat passes up back of the water-leg into the boiler-flues.

Hawley, in 1891, received a patent for an upward and downward draft furnace (Fig. 8), in which there are two grates, *A B* and *C*, employed, the upper one being of water-tubes, *A B*, having connection with water walls, *D*, *E*, and so located that the gases must pass downward through the fuel to reach the combustion chamber. The lower grate *C* is of ordinary construction and is so located that the gases rise in passing to the combustion chamber. The gases from the two fires meet in the combustion chamber *M*, and are there consumed.

Roney, in his patent granted in 1889, shows a steeply inclined grate (Fig. 9), formed of horizontal, flat-topped, overlapping bars, *E*, *E*, so pivoted and connected with operating mechanism as to be continuously and simultaneously rocked on their axes. The fuel is fed from a hopper, *F*, at the top of the grate and is coked as it gradually slides down over the grate bars to the ash-pit. A reciprocating plunger or follower in the bottom of the hopper pushes the coal uniformly onto the grate.

Pratt, in his patent granted in 1890, shows an automatic

stoker (Fig. 10) of the endless-chain-grate type, upon which the fuel is so placed as to form a seal to exclude the access of cold air through the interstices at the sides of the moving grate. He also shows a winged crushing roller, located in the bottom of the hopper for supplying coal to the grate in uniform lumps.

Hopcraft's patent, granted in 1891, shows an inclined, circular, revolving grate (Fig. 11), upon which the fuel is fed centrally from below by a screw conveyer, *M*, formed of sections strung together upon a stationary curved rod or bar, centrally located in the curved conveyer tube, which leads from the bottom of the hopper to the upper face of the grate from below.

The last three patents above mentioned show automatic stokers which are capable of adjustment, so that larger or smaller quantities of coal may be supplied in a given interval.

The Report of the Smoke Abatement Committee, above referred to, states as follows: "The use of mechanical stokers is of the greatest importance in abating smoke. Not only is the saving of labor very considerable, and the saving of fuel most marked, but in nearly all the forms shown in the exhibition, and tested while in operation, smoke was during their working either entirely avoided or much reduced in amount; but most of them require occasional assistance by hand, thus showing that they are still open to further improvement." None of the stokers above described were in existence at the time of this report.

The abatement of the smoke nuisance, so far as steam-boiler furnaces are concerned, does not depend upon the possibility of designing suitable new appliances, but upon the possibility of inducing proprietors to use the appliances already long since designed.

There is no room in this paper to treat of the smoke generated in domestic furnaces, but such have received ample attention on the part of inventors. In most of our cities the smoke nuisance is principally caused by factory chimneys and locomotive stacks.

To abate this nuisance three steps are necessary.

First.—To arouse public interest in the agitation of the question that with the most economical consumption of fuel but little smoke is produced.

Second.—To secure necessary legislation against the nuisance.

Third.—To secure the enforcement of the laws relating thereto.

Fig. 6.

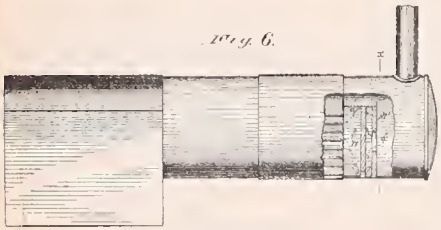


Fig. 8.

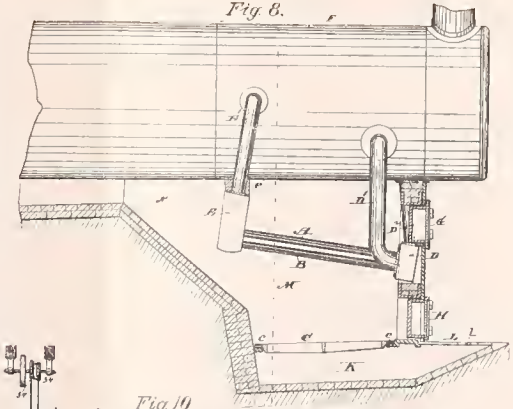


Fig. 9.

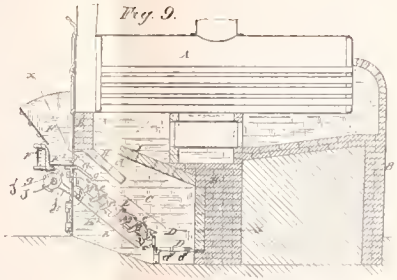


Fig. 7.

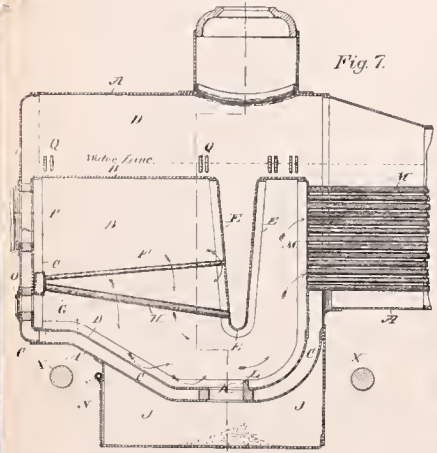


Fig. 10

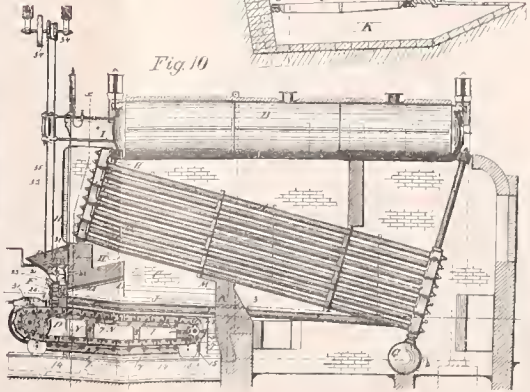


Fig. 11.

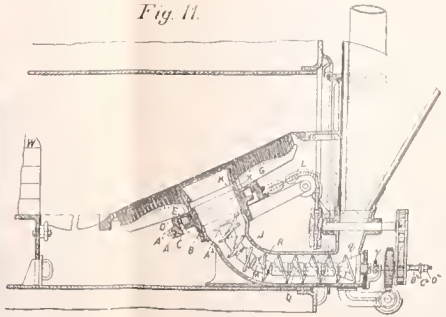
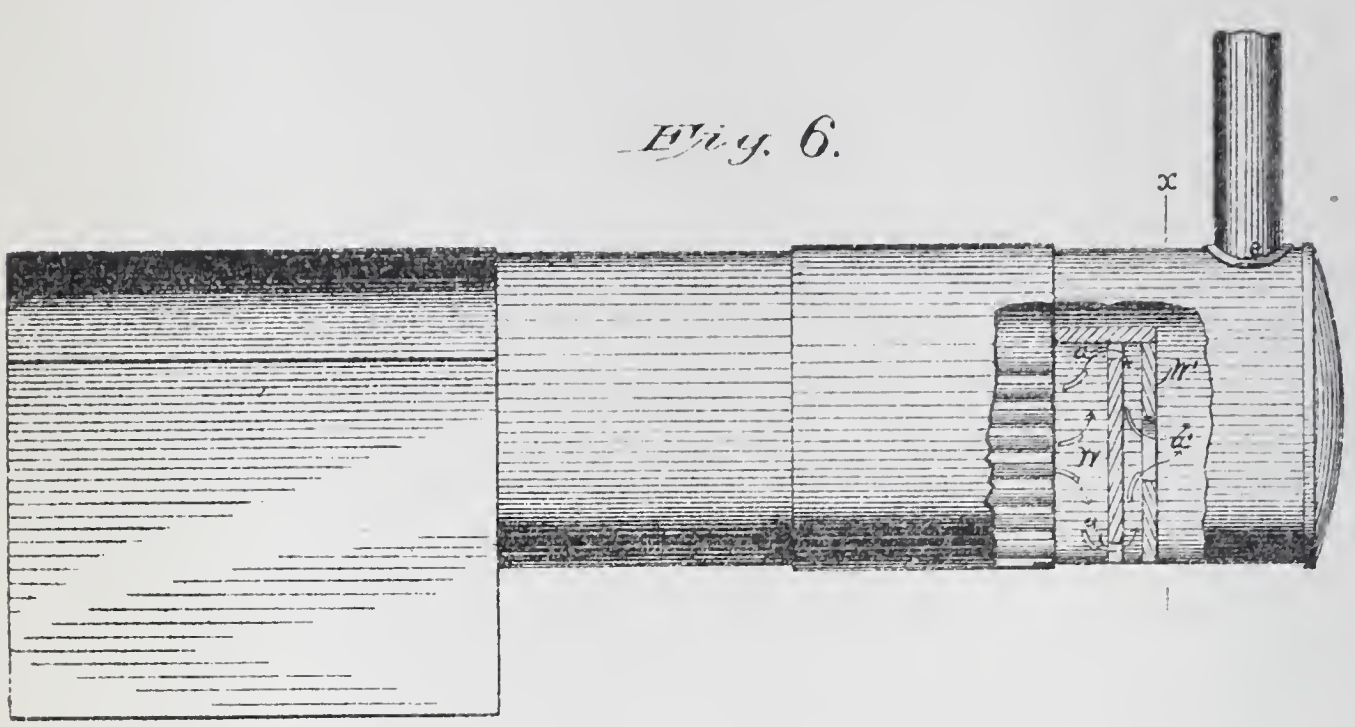


Fig. 6.


x
M'
M
G'

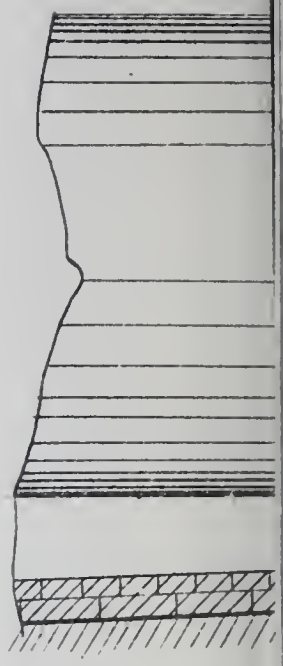
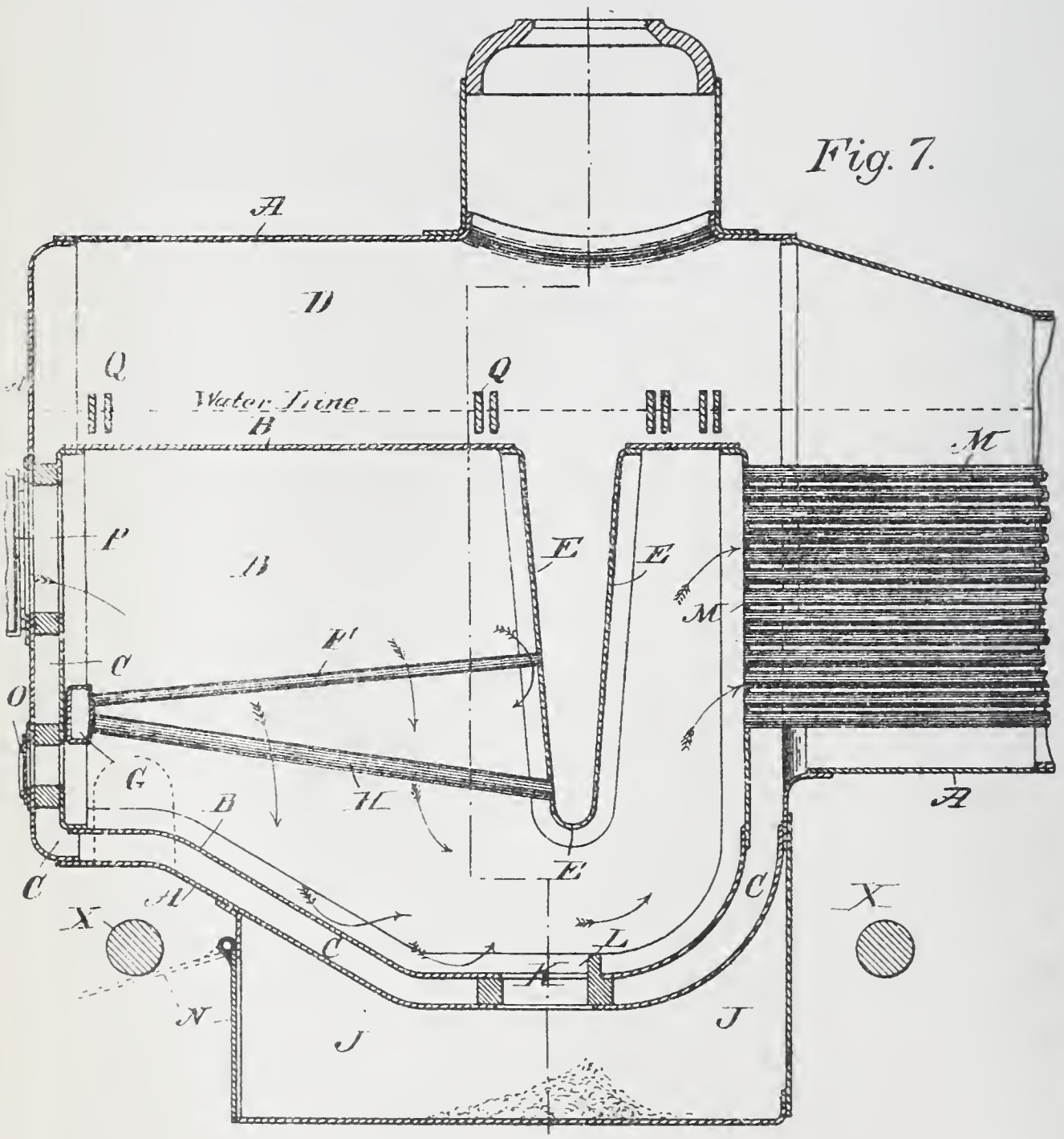
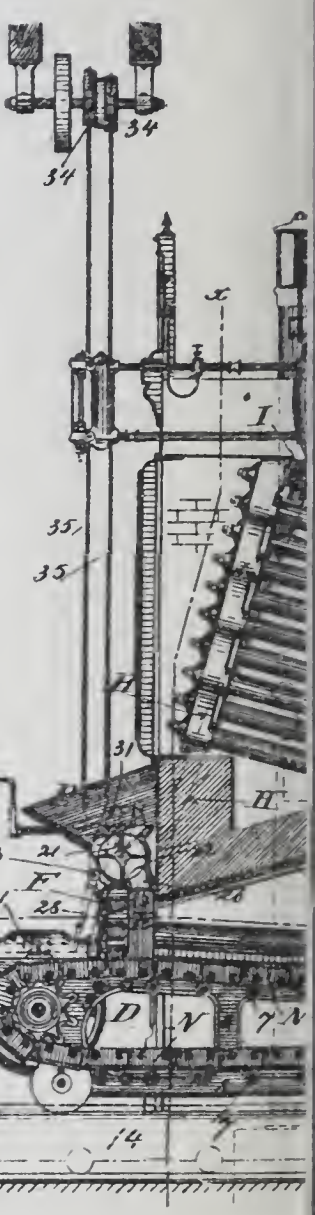


Fig. 7.


A
D
Q
Q
Water Line
B
M
P
B
E
E
M
P'
C
O
G
B
H
C
E
C
X
X
H'
C
L
K
N
J
J


34
34
x
I
35
35
H
31
H'
23
21
F
31
28
D
N
N
14

DISCUSSION.

The Secretary read the following letter from Mr. Russell Taylor, Chief Engineer and Superintendent of Fairmount Park, Active Member of the Club:

H. W. Spangler, Esq., *Chairman.*

Dear Sir: I am in receipt and have considered the matter referred to in your kind favor of October 13, in reference to stopping smoke, etc. I regret that I have not, at present, a means to prevent this trouble. I have no doubt, however, that it is perfectly practical in many instances, as smoke means simply imperfect combustion.

Design a more perfect method of burning coal than that ordinarily in use now, and the smoke or unconsumed carbon will be burned, giving an increase of heat and consequent power.

Yours truly,

Russell Thayer.

Mr. Strong:—It is certainly practicable to abate or obviate the smoke nuisance, but we must first educate the public up to the use of the present devices for both locomotive and stationary engines. The trouble in the West is that the public has settled down in the conviction that there is no remedy.

I find that railway managers generally believe that a soft-coal engine inevitably smokes. If we provide a device which prevents this, they take no interest in it until compelled to do so by competition.

The Erie road, moved by this consideration, used on alternate weeks soft coal, with a smoke-consuming device, and hard coal, and succeeded so well with the former that the conductors could not tell when soft and when hard coal was being used. Most designers of fire bridge walls use a hollow bridge with openings in the back, but these openings become sealed by slag in about twenty-four hours. There should be a hollow box supplying air under the grate, the bricks overlapping so as to admit the air.

Mr. Livingston:—Every effort was made in Pittsburg to abate the smoke nuisance; a number of patents were faithfully tried, but all to no purpose. It is, of course, possible to prevent the emission of smoke, but it costs more than it comes to. The

proper remedy is first to convert the soft coal into gas, and then to burn the gas.

Mr. Spangler, for the Committee on Information and Entertainment, called attention to a newspaper account of the Chicago and Alton locomotive, with its smoke-burning device. The newspaper account represents the device as a great success. The General Manager of the road reports the inventor deceased and the apparatus removed.

A patentee in West Philadelphia conceived the idea of fanning the smoke back into and through the fire, not so much as to prevent the emission of smoke as to increase the efficiency of his boiler. The plant is still to be seen in West Philadelphia, and the inventor would be pleased to show it to inquirers.

Mr. John D. Baltz.—Mr. Baltz spoke especially of the fine houses recently erected in West Philadelphia on the Bluff, affording an extended and beautiful view of the Schuylkill River and East Park—close to the P. R. R.—near the site of the proposed River-View Park at Thirty-fourth Street, where many of the occupants found that the smoke ascending from the engines immediately below them made its way through doors and windows and into the hot-air flues of their furnaces, and thus was introduced into every part of the house, greatly damaging carpets, curtains, furniture and linen, etc. Mr. Edward Brill, who lives close to the railroad, put on extra weather-strips—all to no purpose. This is not the only locality in the city so seriously affected; loud complaints are heard all along this railroad. A committee was formed, the railroad officials were waited upon, and promises made which apparently were not fulfilled; so an ordinance to remedy the evil was offered in City Councils, which is still pending before that body. Suits were also instituted in the courts for the recovery of damages sustained, and the litigants think they will be successful in their suits, not only recovering for the depreciation of their property, but for the inconvenience and discomfort caused by the "noise, smoke, and odors," which it is for the jury to measure, as was done in the Supreme Court of the United States in 1883 in Baltimore and Potomac R. R. Co. *vs.* Fifth Baptist Church. It is not unreasonable to insist that the railroad companies shall abate this growing evil, especially within the

city limits, by burning hard coal, or coke, or by applying some of the various devices for more perfect combustion, which means are within their reasonable control. The citizens believe that they will soon be heard and relief granted.

The Baltimore and Ohio R. R. uses coke on all its passenger engines, much to the comfort of the traveling public and our citizens along its line, and we see no smoke from the Reading railroad's hard-coal-burning locomotives.

Mr. Walter C. Kerr.—Mr. Kerr stated that mechanical stokers were designed primarily to secure economy of combustion, and only secondarily to reduce smoke.

Chicago was one of the first cities to move against the smoke nuisance. It passed laws, and it tries to live up to them. Some 1,500 good citizens are pulled up and fined once a month. In Chicago, owing to the treacherous ground, many large buildings are built on concrete foundations, resting upon a continuous floor of steel rails. Boilers have been generally set close to this floor-line, and we cannot now cut through it to introduce any device requiring room below the grate. The consumers content themselves with paying the fines.

Chicago is now stimulated to the utmost by the project of the Columbian Exhibition. She is exceedingly anxious to show to the world that her atmosphere is transparent, and if there is anything that popular feeling can do to abate the smoke nuisance, it will be done in Chicago within the next two years.

Legislation may control the railroads, but I doubt whether it will have much effect upon the factories. The manufacturer's pocket is in the way. Any device for obviating smoke must, to be successful, show a substantial saving in fuel or labor. Mechanical stokers will prevent smoke if properly managed, but where smoke is not an objection they are, generally, not so handled, and the smoke continues.

Hundreds of smoke-preventing devices have appeared. Many apparently successful ones depend upon the admission of a great surplus of air, but this, of course, means mere dilution, with a reduction of efficiency, which has brought smoke-preventing devices as a class into disrepute.

No amount of air space in the grate will avail if the coal

breaks up and packs closely, thus clogging the draught. To prevent this, rocking grates are devised, to break up the fire and allow the air to pass through it.

What is wanted is reform in the manner of setting boilers rather than in legislation.

Mr. T. Carpenter Smith:—Some years ago I helped to put in and operate a mechanical stoker of the continuous-chain-grate pattern under a Cornish boiler. This was for smoke prevention rather than for stoking. A high bridge wall was first used, and the smoke continued, and the boiler was less efficient than was hoped. The bridge wall was reduced in height, and the smoke in amount, but the stokers were found costly to repair and were abandoned.

In England and Scotland deep copper fire-boxes were formerly used on locomotives. At first the burning out of the fire-boxes was a serious item. A brick arch was strung across the fire-boxes, but the sheets burned away over the door, and the boilers did not steam so well. Propping the furnace door open with a shovel was found to make a great improvement. The space between the brick arch and the tube sheet became clogged up with ashes, which had to be cleaned out at the end of each trip.

Mr. Kerr:—Such devices are useful on locomotives, where there is an abundance of draught, but on stationary engines they are a failure. In a locomotive boiler the fire bridge is an advantage because it checks the draught. In a stationary boiler there is scarcely draught enough to begin with.

Mr. Henry G. Morris:—I would ask whether the work of Chas. Wye Williams, published in 1858, has been lost sight of. I think nearly all the points brought out in the evening's discussion will be found there. The summing up of the subject was that smoke prevention did not pay.

Mr. Baltz:—I understand that a number of citizens along West Green Street called upon the Baldwin works in relation to the smoke produced by them, with the result that that particular trouble was greatly diminished to the entire satisfaction of the citizens in question. This was done by using hard coal and oil, instead of soft coal, and by changing the mode of firing, which proves a great saving to the company in daily expenses.

X.

LIMITATIONS OF ELECTRIC TRANSMISSION.

By A. Saunders Morris, Active Member of the Club.

Read February 20, 1892.

This paper is not intended as a purely scientific discussion of the limitations of electric transmission of power, but simply to make more evident some of the considerations which govern it, and the reasons which determine the choice of motors and generators.

Motors may be divided into two general classes or types: first, those for direct or continuous current; second, those for alternating. The first class may be subdivided into series and shunt wound, the difference being in the method of magnetizing their fields. Alternating motors may also be subdivided into two classes: single-phase and multiphase. Again, both single-phase and multiphase may be synchronous or non-synchronous. The former have a certain fixed speed which depends on the speed of the generator, while the latter are independent of the generator speed. The general characteristics of direct-current motors are, for series wound, very strong starting torque and very poor speed regulation; that is, when the load is thrown off, the motor will speed up possibly to a dangerous point. Its chief uses are for street railway work, hoisting and similar purposes, where strong starting torque is a requisite, and where the load is constant or the speed may be regulated by hand.

The characteristics of the shunt motor are fair-starting torque and close-speed regulation, and of course from this it follows that a shunt motor can never run away.

All direct-current motors are provided with a commutator, which is to the motor almost what the valve mechanism is to the steam engine, and has proved to be its most troublesome part. This is partly due to mechanical difficulty in assembling and holding together the numerous parts necessary, and partly to electrical difficulties, which increase very rapidly as the electromotive force and quantity of current rise. This, then, places a practical limit to the electromotive force and to the current, and

hence to the distance to which power can be economically transmitted as well as to the amount of power.

Alternating motors of the non-synchronous single-phase type have not come into practical use for power transmission. As yet their efficiency is low, and they are only suitable for light powers, such as running fans, sewing-machines and the like.

Single-phase synchronous motors are coming into use and undoubtedly have a large field before them, owing to their high efficiency and the absence of commutators. Their characteristics are, constant speeds under all loads and no starting torque. They may be so wound as to be capable of bringing themselves up to speed without load. When the proper speed is reached the motor is practically locked to the generator, and full load may be thrown on without fear of pulling the motor out of synchronism with the generator. Another method of bringing the motor up to speed is to attach a small self-starting motor of sufficient power to bring the synchronous motor up to speed, and when this point is reached the current is switched from the small motor to the large, and the load is thrown on.

Multiphase motors may also be divided into synchronous and non-synchronous; but the synchronous "multiphasers" have the advantage over synchronous "single-phasers," that they are self-starting without any special winding.

As an example of the non-synchronous multiphase motors, I may mention the Shallenberger motor and the Tesla motor, both of which have been carefully worked up by the Westinghouse Electric and Manufacturing Co. The former, while apparently a single-phase motor, is in reality a "multiphaser," although there are but two wires leading to it, the current differing in phase from the primary being produced by inductive action in a small coil inclined to the main coil. The armature in this case is a simple iron disk.

In the non-synchronous Tesla motor, currents differing in phase pass around adjacent field coils, inducing currents in the armature which cause rotation. The wires on the armature are short-circuited, and hence no commutator or collector is used. This point makes it especially valuable for use in mines, etc., for the form of the motor makes a dirt-proof case; and as the circuit is

never interrupted in the motor as it would be on a commutator, there is no danger from explosion in fiery mines. In regulation and efficiency it compares very favorably with direct-current shunt-wound motors and weighs less for a given output; this point is valuable when the motor is mounted on a mining machine or where portability is required.

In addition to a good starting torque, synchronous "multiphasers," as represented by the Tesla motors, have, of course, speed regulation and no commutators, the current entering the armature through three or more solid rings or collectors.

We have now seen the general characteristics of different types of motors, but let us analyze these a little more carefully in order to see where different types fail.

Owing to the presence of the commutator, the direct current cannot be satisfactorily worked at potentials greatly exceeding 1,000 volts, and hence for long distances either the outlay for copper conductor may become so great, or the plant efficiency may become so low, that it will not be a financial success.

With alternating motors, however, the electromotive force may be carried to 5,000 volts, and, for very long distances, by the use of raising and lowering converters, we may readily increase the electromotive force on the line and still maintain a relatively low electromotive force on the generators and motors. This has been found desirable owing to the difficulty of insulating moving parts.

The efficiency of converters may be taken at 96 per cent., and that of motors and generators will be at least as high as 90 per cent. each, so that we have, leaving the line out of the question, a plant efficiency of about 74.5 per cent. if converters are used, and, of course, 81 per cent. if their use can be dispensed with. In other words, the distance may be so great that the saving in copper due to the higher potential will balance the additional cost of converters as well as the decrease in plant efficiency due to their use. Usual line losses will vary from 5 to 25 per cent., and hence the total plant efficiency, counting from the power applied to the generator pulley to that given out by the motor pulley, would vary from 56 to 71 per cent. if converters are used, and from 61 to 75 per cent. if the voltage is low enough to dispense with them.

A point in favor of electric transmission is, that the plant efficiency is almost constant under wide variations of load, and by a certain proportion of line loss it can be made to vary less than one per cent. between full and half load. Thus with a generator and motor efficiency of 90 per cent. each at full load, and of 85 per cent. at half load, we find that a line efficiency of 80.4 per cent. will give a uniform plant efficiency of 65 per cent. This is due to the fact that as the motor and generator efficiencies decrease, the line efficiency increases.

One of the first points to be considered in power transmission is the value of a horse-power produced at the point where power is required, by means of a steam engine or other available prime mover, and also the cost of producing a horse-power at the proposed generating station. A comparison of these figures will give an approximate idea of how much must be allowed for losses in transmission when the interest and depreciation are allowed for. Of course, as the efficiency of the line is increased its cost is increased, if the electromotive force at the motor remains constant, but, on the other hand, the generator and prime mover will cost less for the same power delivered by the motor. Suppose, instead of increasing the line efficiency by increasing the size of conductor, we double the electromotive force—we have now increased the plant efficiency, but the motor and generator may cost more on account of the increased electromotive force. It will be seen that there are several variables dependent on each other.

By increasing the electromotive force the size of wire may be reduced indefinitely; but there is a mechanical limit to the size which will stand climatic strains, and this, of course, will depend on the character of the country through which the line passes.

High potential is a mere relative term, for not many years ago 500 volts were regarded as high; but we have gone up step by step, until last summer, some of you may have witnessed the experiment made abroad of transmitting power at a potential of 12,000 volts or even higher, and the day is possibly not far distant when we shall see this voltage in common use for long-distance transmission.

In this country, probably the highest potential used on a motor

in actual service is at a plant in Colorado, mentioned in a previous paper. The potential at the motor terminals is 3,000 volts, and its record up to the last time heard from, about three months ago, was that it had been running continuously 156 hours a week for five months. The plant is shut down on Sundays only, from 7 A.M. to 7 P.M., and the total stoppages of the mill due to the transmission plant have been less than one per cent. One-half of this delay was for inspection of the line and building a crane to lift out the armature.

The choice of motors best suited to the work to be done is an important point in the design of a power plant; for it must be readily seen that a constant-speed motor, such as a direct-current shunt motor or an alternating-current synchronous motor, is not the proper one to put under a street car, nor, in general, is the direct-current series motor the proper one to install where the load is variable but the speed required is constant.

In conclusion, in order to get the best financial results from a power plant, the engineer must consider carefully the class of work to be done, the potential which will give him the minimum cost of plant, giving due consideration to the line loss on which will depend, in general, the efficiency of plant.

MONCURE ROBINSON.

Born ———— —, 1802; Died November 10, 1891.

On the 10th of November our Club lost its oldest Honorary Member. Full of years, with an unsullied reputation achieved when few of us were even born, Mr. Moncure Robinson was, perhaps, the last link which connected the great creators of railroad transportation with those who are to-day reaping the benefits of the enormous wealth which the railroads have concentrated in the cities of the world. By Philadelphians especially, the first Chief Engineer of the Philadelphia and Reading Railroad should receive the credit and homage which are due to him for its excellent location, which has given to us the cheap coal that has been the secret of our manufacturing success. To Mr. Robinson is due not only the location of the road—which has a grade so adjusted to the country that the tractive force necessary to take the empty cars from tide-water to the mines is just equal to that required for pulling the loaded ones down, so accomplishing the work with the least expenditure of power—but he was also instrumental, by his clear financial abilities, in maintaining the credit of the road and negotiating its bonds in some trying periods of its early existence.

To obtain the location, contour-line maps were made, probably the first in this country for the purpose; actual contours, or "bend levels," as they were called, being marked out on the ground. This was in accordance with the methods pursued in France in locating the canals, which had been studied by Mr. Robinson for several years.

He was born in 1802, belonging to a family that was distinguished in the early colonial history of Virginia. The first of the name in America, a brother of the Bishop of London, came to Virginia about the year 1666, and became Secretary of the colony. One of his sons was President of the Council and acting Governor, and a grandson occupied the very important office of Speaker of the House of Burgesses. Mr. Moncure Robinson was descended from the third son of the immigrant. He presented a fine specimen of the English race. Very tall, with an imposing figure, a vigorous frame and a striking face, he was

sure to attract attention, even before his charming manners captivated those who were thrown in contact with him.

On returning from France, in 1827, he stayed for a time in England, which was just then in the midst of a heated discussion over the construction of a railroad between Liverpool and Manchester, and in which the partisans of horse-power, stationary engines and locomotives tried to persuade a committee of Parliament of the advantages of their own and the disadvantages of their opponents' methods. With excellent judgment, Mr. Robinson saw the great future of the locomotive, and soon left his position on the James River Canal to connect himself with the future great invention of the century. In 1828 he came to our State to make the survey for the Pottsville and Danville Railroad, for Stephen Girard, and afterward of the Allegheny Portage Railroad, and he has resided here the greater portion of the time since. He soon after built the Petersburg Railroad in Virginia, and the Richmond and Petersburg, Richmond and Fredericksburg, and Winchester and Potomac, and, in 1833, the Little Schuylkill Railroad. In 1834 he began the Philadelphia and Reading Railroad. In 1840 the Russian Government tried to secure his services, but his wife was opposed to going so far away, and he was instrumental in introducing Messrs. Eastwick and Harrison, then just beginning to build locomotives for the Reading Railroad, and these gentlemen built the first railroad in Russia. In 1842 Mr. Robinson reported to the United States Government on a dry dock for New York Harbor. In 1847 he retired from the active practice of his profession, and has lived here quietly ever since. Although he has never been able to join in the proceedings of our Club, he always manifested a warm interest in it, and was always ready to give it any advice which his long experience made valuable.

Further details of the various projects with which he was connected are to be found in the interesting "Professional Biography" published two years ago by the J. B. Lippincott Company, and written by my colleague on the committee, Richard B. Osborne, Esq.

T. M. C.

RICHARD HENRY LEE.

Richard Henry Lee, late Active Member of this Club, and Superintendent of the Logan Iron and Steel Company at Lewistown, Pennsylvania, met his death by accident on the night of December 28, 1891. It is believed that in walking across a railroad bridge, on his way to the works, he slipped and fell between the ties, and was killed, nearly or quite instantly, by the fall. His body was found the next morning, after hours of search, in the stream, about a mile below the bridge.

Mr. Lee was a lineal descendant of Richard Henry Lee, one of the signers of the Declaration of Independence, and second cousin of the late Confederate General Robert E. Lee.

He was born at Leesburg, Virginia, August 2, 1831, and was thus a little over sixty years of age at the time of his death. In 1847, when only sixteen years of age and the youngest member of his class, he graduated from Washington College, Pennsylvania. Among his classmates at that institution was James G. Blaine, now Secretary of State.

During his subsequent engineering career he served as chief engineer for several Southern railroads, and as the Government Engineer in charge of the improvement of the harbor of Beaufort, North Carolina. During the War of Secession he was engaged at the Fort Pitt Works as Assistant Superintendent in charge of the testing department.

At the close of the war, in 1865, he became Superintendent of the Freedom Iron Works, and retained this position, together with that of President of the Lewistown Water Company, until the time of his death.

Mr. Lee was a member of St. Mark's Episcopal Church, Lewistown, and for many years Rector's Warden in that parish.

EDWARD NICHOLS.

Edward Nichols, late Active Member of the Club, died on Thursday morning, January 7, of pleuro-pneumonia, the exciting cause being exposure on the occasion of a fire on the night of December 31, at the Brooks Locomotive Works, Dunkirk, New York, of which establishment Mr. Nichols was President.

He was born in Middlebury, Vermont, September 13, 1850, but his boyhood and early manhood were spent at Tarrytown, New York. At the age of thirteen, after the death of his father, he entered the Military Academy at Sing Sing, New York. From his sixteenth to his twenty-second year he attended the Rensselaer Polytechnic Institute at Troy, New York, as a student of metallurgical and mining engineering, and later as Professor of Chemistry. During 1875 and 1876 he traveled in Europe, forming a more intimate acquaintance with European engineering practice and with foreign languages.

At the Centennial Exhibition of 1876, Mr. Nichols acted, by appointment of the American Institute of Mining Engineers, as Secretary of the Committee for the Entertainment of Visiting Foreign Engineers. In 1879 he found himself in charge of a blast furnace at Hermitage, Georgia, erected by a company in which he was interested, together with the Messrs. Burnham, of the Baldwin Locomotive Works of this city, and Burden, of Troy, New York. While holding this position, he was appointed State Geologist of Georgia. In 1884 he married a daughter of Mr. H. G. Brooks, then President of the Brooks Locomotive Works at Dunkirk, New York. She removed with him to Columbus, Ohio, but died about a year later.

In 1885 Mr. Nichols was elected Vice-President and General Manager of the Warren-Scharf Asphalt Paving Company, and in July, 1887, President of the Brooks Locomotive Works, in the place of his father-in-law, deceased. This office he continued to hold until the time of his death.

NOTES AND COMMUNICATIONS.

GOVERNMENT TIMBER TESTS.

Mr. Fernow, Chief of Forestry Division, United States Department of Agriculture, October 17, 1891.—It is, perhaps, unnecessary to remark, before a body of engineers, that our knowledge of timbers is very imperfect; in fact, "our knowledge of timber may be described as a state of ignorance."

Everybody knows that wood is exceedingly variable in its qualities; it is the factor of "life" that makes the quality of wood so variable. While in the manufacture of iron and other building materials, we have it more or less in our hands to make them of given quality, we are not well enough acquainted with the physiology of timber to even recognize its qualities by a simple examination.

The object of the present work undertaken by the Forestry Division of the Department of Agriculture is threefold. First, to obtain a better knowledge of the quality of our commonest commercial timbers; secondly, to devise means of relating qualities to physical structure and appearance; thirdly, to establish, if possible, the influence which divers conditions of growth exercise upon the quality.

These objects can be attained only by a very large number of tests on material of known origin, carefully examined as to its anatomical structure and physical condition.

We are investigating not only the strengths of the specimens submitted, but all other conditions affecting their usefulness in service. Exhaustive records are preserved in duplicate, stating in the minutest detail all the circumstances observed with respect to each specimen; the locality where it was cut, with its geological and climatological features; an exact description of the site and exposure, the soil, the surrounding growth and undergrowth; the origin of the tree, its age and dimensions; the positions in the tree of the various test-pieces submitted, etc., and it is expected to subject to the regular series of tests from 1,000 to 2,000 test-pieces of each species.

While from the large number of tests our knowledge of the capabilities of each species and of their range of strength will be advantageously increased, the main and most important, as well as the most difficult part of the work lies in the physical examination of the test-material and the relating of the results of the latter to the test results. When we are through with the work, we hope to enable the engineer or architect not only to specify for timber of given quality, but also, by a rapid macroscopic and microscopic examination, to pass on each stick as to its coming up to the specification, and, furthermore, to acquaint us with the conditions of growth that produce given quality.

While this is the ideal object, attainable probably only in part, it is evident that an enormous amount of new knowledge regarding one of our most important materials of construction must result by the way.

The vastness of the undertaking involved in anything like such an adequate series of timber-tests points to the conclusion that the National Government alone is competent to grapple with it. For while this work has been inaugurated on a small scale with the scanty appropriation for the Forestry Division, it becomes now of the

first importance that the means should be forthcoming which alone will enable us to prosecute the work in an acceptable manner, and those who are conducting the tests are now chiefly anxious that the engineers of the country shall make known to Congress, through the Department of Agriculture, their estimate of the importance to the country of the knowledge to be gained, in the hope that the needed appropriation may be granted

Mr. Fernow referred to the gentlemen associated with him in this work, and explained more in detail and illustrated by photographs, blank forms, etc., the methods pursued in the collecting, testing, examining, recording and relating of results, all of which will be presently described more fully in an official bulletin, accessible to every engineer. He also called special attention to several separate series of tests contemplated and in progress, such as the testing of large beams to ascertain the relation of such tests to those on small specimens, an investigation into the influence of seasoning and the effect of turpentine orcharding on pine timbers, etc. He also exhibited a large number of letters from leading engineers indorsing the work, and assured the Club that the many problems involved would be attacked and followed up in proportion to the interest shown by those to be benefited by the work and to the appropriations granted for it.

The following is a copy of the record as made for each tree, showing the care taken in preserving all the data relating to each sample:*

Name of collector, *Chas. Mohr.* Species, *Pinus Palustris.*

Station (denoted by capital letter) *B.*

State: *Alabama;* county: *Clark;* town: *Thomasville.*

Longitude, 86° 45′; latitude, 32° 4′; average altitude, 380′.

General configuration: plain, hills, plateau, mountainous; general trend of valleys or hills: *E. S. E. to N. W.*

Climatic features: *Subtropical, mean annual temperature,* 66° *F.; ranges from about* 19° *to* 100°; *mean annual precipitation* 56 *to* 60, *no exact data; average direction of wind in winter, from S. E.; in summer, from S. E. to S. W., and in fall, W. to S. W.*

Site (denoted by small letter).

Aspect: Level, ravine, cove, bench, slope (angle approximately): 20 *to* 40°.

Exposure: Elevation (above average station altitude) 250 *feet.*

Soil Conditions:

1. Geological formation (if known): *Lowest Eocene, Burstone.*
2. Mineral Composition: clay, limestone, loam, marl, sandy loam, loamy sand, sand *somewhat.*
3. Surface cover: bare, grassy, mossy; leaf cover abundant, scanty, lacking.
4. Depth of vegetable mould (humus) absent, moderate, plenty; or give depth in inches. *Scanty.*
5. Grain, consistency and admixtures: very fine, fine, medium, coarse; porous, light, loose, moderately loose, compact, binding, stones or rocks, size of:

* Descriptive words are either underscored or added (in italics).

6. Moisture conditions: wet, moist, fresh to dry, arid; well drained, liable to overflow, swampy; near stream or spring or other kind of water supply:
7. Color: *Ashy.*
8. Depth to subsoil (if known): shallow, 6 inches to 1 foot, 1 foot to 4 feet deep; over 4 feet very deep, shifting.
9. Nature of subsoil (if ascertainable): *fine, sandy, red, ferruginous, loam, damp.*

Forest conditions:

Mixed timber, pure, dense growth, moderately dense to open.

Associated species: *Black Jack Oak, Spanish Oak, Dogwood.*

Proportions of these: *all equally in very small proportions, not reaching* 10%.

Average height: *None above medium height, i.e., from* 30 *to* 40 *feet.*

Undergrowth: *Scrubby growth of above hardwoods, with Vaccinium Staminilum.*

Conditions in the open: field, pasture, lawn, clearing (how long cleared).

Pinus Taeda, with P. echinata; cleared about twenty-five years ago.

Nature of soil cover, if any: weeds, brush, sod: *brush of pine and hardwoods.*

Pinus Palustris rarely seen, and of crippled growth.

STATION: *B.* SITE: *a.* SPECIES: *P. Palustris.* TREE NO.: 16.

Position of tree (if any special point notable not appearing in general description of site, exceptional exposure to light or dense position, etc., protected by buildings, note). *On gentle decline W., S. W.; crown partially covered, N. to E., not touching and free S. and W.*

Origin of tree (if ascertainable, natural seeding, sprout from stump artificial planting).

Diameter breast-high: 20 *inches.* Height of stump: 3 *feet.*
Height to first limb: 56 *feet.* Length of felled tree: 105 *feet.*
Age (annual rings on stump): 202. Total height: 108 *feet.*

No. of disks.	Distance from butt.	Weight of combined disk pieces.	Diameter (N.-S.). (*All disks measured 6 inches in height.*)
1	9″	24 lbs. 0 oz.	
2	19′ 3″	18 " 7 "	
3	31′ 9″	15 " 0 "	15½″
4	44′ 3″	14 " 3 "	12½″
5	54′ 3″	13 " 4 "	12″
6	64′ 3″	*rejected, too knotty for splitting.*	
7	74′ 9″	7 lbs. 0 oz.	

No. of log.	Distance from butt.	Length of log.	Diameter butt-end.	Annual rings at butt-end.
1	15″	12′	20″	200
2	13′ 3″	6′	19½″	
3	19′ 9″	12′	16″	196
4	32′ 3″	12′	15″	

No. 2 *for Mr. Roth no disk taken; radial fissure above butt very small; timber sound, without limb-knots to length of* 44 *feet.*

STATION: *B.* SITE: *a.* SPECIES: *P. Palustris.*

YOUNG TREE, No. XXI.

Diameter breast-high: 4 *inches.* Total height: 45 *feet.*

Disk No.	Distance from butt.	Weight of disk.
1	*none*	3 lbs. 10 oz.
2	2′	2 " 12 "
3	6′	2 " 8 "
4	10′	2 " 6 "
5	14′	2 " 2 "
6	18′	2 " 3 "
7	22′	1 " 12 "
8	26′	1 " 6 "
9	30′	1 " —
10	34′	— 12 "
11	38′	— 8 "
12	42′	— 4 "

Remarks:—*In small oak opening, not over an acre in extent. On this site and corresponding localities of the station, openings are rarely met with in the pine forest, and when occurring are of small extent. Few pines are found below six inches in diameter, their place being almost exclusively taken by Black Jack, Spanish Oak and more rarely by Post Oak and by Dogwood; a scrubby growth of these hardwood trees and of Black Gum forming dense undergrowth, amongst which Vaccinium Staminilum takes a large share; bearing testimony of the poverty of the soil prevailing in those hills. The few pines below two and three inches observed were of a stunted and sickly growth, caused by repeated forest fires.*

Mr. E. E. RUSSELL TRATMAN, Associate Editor of *Engineering News*, was introduced to the meeting and said: In adding a few remarks to the subject of tests of timber, as presented by Mr. Fernow, I need not do more than briefly refer to the importance of such a thorough, comprehensive and systematic series of tests as has now been commenced under the Forestry Division. Every engineer, as well as every architect, builder, and others who employ timber largely for constructive purposes, will at once recognize the importance of these tests, and the value of the recorded results based upon such careful tests. Reference to this matter reminds me that in the South Kensington Museum, London, are a number of frames containing test specimens of various kinds of wood which have been tested and broken, the results and other particulars being noted on a label attached to each specimen. In regard to microscopic examinations, the value of these will be specially recognized by any one who has read the report of Mr. P. H. Dudley on "The Structure of Certain Timber Ties; Behavior and Causes of their Decay in the Roadbed," which was published in 1887 in Bulletin No. 1 of the Forestry Division, U. S. Department of Agriculture. In that report Mr. Dudley stated that the decay of timber, formerly ascribed to slow combustion, is now known to be due to various kinds of fungi, the presence of many of which has been demonstrated by microscopical investigations. These fungi are the inducing causes of decay. The report then considers the structure and nature of some of the timbers largely used for railway purposes. In these investigations the microscopic examinations formed a very important part, and a series of photo-micrographs is given, showing the structure of the different timbers. This

report, although dealing only with a limited number of species of timber, is, I think, one of the most valuable and practically useful contributions to the literature upon this and kindred subjects. There is a large amount of published scattered information in regard to the properties and qualities of timbers in this country and abroad, and I suggest that it would be advisable for the Forestry Division to keep a record or bibliography of such published information. The tests should also include timber treated by preservative processes. In this country a very large amount of soft wood is used for railway ties, which has led to the use of steel tie-plates under the rail for purposes of economy. With the harder woods this is not necessary. Australia has not to provide such means to increase durability, as the ties are of native hardwood, and the abrasion of the surface is lessened by holding the rails firmly to the ties by bolts as well as spikes. The following are the weights per cubic foot of some of the timbers extensively used for railway ties:

United States.	Weight.
Post oak	52.14
Chestnut oak	46.73
White oak	46.35
Yellow pine	43.62
Chestnut	28.07
Hemlock	26.42
White cedar	20.70
Australia.	
Blue gum	65.00
Red gum, sugar gum, jarral	63.00
Karri	61.00

Much has been said lately of the desirability of having government control of the forest property, and in this connection I have been interested in looking up the review of forest administration in British India for the year 1887–1888. The aggregate area of the provinces under the management and control of the Forestry Department was 812,709 square miles, of which 97,386 square miles, or 11 per cent., was forest area, which already yielded about $1,400,000 net return to the government, or nearly $14 per square mile. The forests are worked for revenue in a proper business-like manner, a certain output being made of timber and fuel. The protection of the forest areas from fire and cattle has been successfully managed, and the artificial reproduction of forests is encouraged, while experiments are carried on in growing exotic trees, etc. The results obtained in India should be encouraging to those who are working for forest preservation in this country.

PURCHASING CEMENT FOR LARGE WORK.

With the growth of engineering works in the United States, and the immense increase of high buildings in the great cities, this country is rapidly becoming one of the largest markets for Portland cement in the world. When we were a young country, engineering works were on a modest scale, and the natural cements, such as Rosendale, Louisville, Union, and cements of that grade, were sufficient to meet the ordinary requirements of such works; and in the construction of large public edi-

fices and very large buildings of early American days, lime mortar was considered sufficiently strong for all practical purposes, as the question of time and the interest account on the land were not prime factors in the cost. To-day, immense engineering works, of gigantic character and involving great amounts of money, public buildings and immense office buildings, are going up constantly, time is an element of consideration, and the interest account far more than counterbalances the difference in cost between Portland-cement mortar and lime mortar. Hence, Portland cement is rapidly taking the place of all other ingredients for mortar-making, not only because of its great initial strength, but also because, by its use, work can be carried on all the year round.

In view of these facts, a very interesting line of thought is opened up, in the question of how to buy Portland cement for use in works of the magnitude described, and also as to whether there is not some middle-ground between the low-priced American cement and the high-priced Portland cement, which is safe for the engineer and contractor to stand upon. Considering the subject in its broadest light, the first point involved is the strength of the mortar. The proper way to buy cement is to buy it not upon the ordinary test of neat cement, but upon its mortar-giving qualities. It is a well-known fact that the clinker produced in the manufacture of Portland cement, taken from the same kiln, ground in the same mills, will give very different tensile strains neat, according to whether the resultant cement be fine-ground or coarse-ground.

A coarse-ground Portland cement will give a very high, neat test at seven days; a fine-ground Portland cement will give a low test neat at seven days. By the average cement buyer preference would be given to the cement of high tensile strain, when, in point of fact, if the two cements described are mixed with sand, the fine-ground cement will make much the better and stronger mortar.

The manufacturer, naturally, is interested in selling the cement that costs him the least to make, and the difference between grinding his product to a fineness of 70 per cent. on a 10,000-mesh sieve, or to a fineness of 90 per cent. on a 10,000-mesh sieve, is very great in favor of the coarse-ground product. His mills will turn out more; his engine will labor less, and his cost of grinding, per barrel, will be very materially reduced. There are, however, manufacturers who believe in quality, in preference to cost; and if engineers and architects would insist upon purchasing cement according to its mortar-giving qualities, instead of its neat seven-day test, more manufacturers would be brought to the same conclusion.

A very simple and recent illustration of this fact has been shown in the construction of the East Jersey Water Company's dams, involving over 100,000 yards of masonry, in and around Newfoundland, Oak Ridge and Clinton, N. J.

In the purchase of cement for this work, an important step has been made in what is practically a new method of purchasing cement in this country. Specifications covering the usual requirements for fineness, freedom from lime, checking, and tensile strain, neat, with two parts sand, and with three parts sand, were sent out to a number of bidders. In these specifications, the fineness to be guaranteed was left in blank, the time of setting was left in blank, and the tensile strain, neat, with two parts sand, and with three parts sand, was likewise left in blank. These blanks were then filled up by the several manufacturers, each one guaranteeing what he would sell for a given price. It then became a very easy matter for the engineer, Mr.

Clemens Herschel, the well-known hydraulic expert, to determine, by comparison with the specifications of the American Society of Civil Engineers for cement neat and in various sand mixtures, which of the several cements was cheapest per yard of cement mortar of the desired strength for his work, taking into consideration the price bid for the cement, the cost of his sand, and the guaranteed strain for mortar with two parts of sand and for three parts of sand.

In the case in question, the contract was awarded to the "Improved Union" Cement, made by the American Cement Company, Egypt, Lehigh County, Penna., upon a guarantee that the three-to-one mortar would give as high a tensile strain as the two-to-one mortar offered by the average Rosendale manufacturer; and the result of the work has more than justified the experiment, as regards both quality and cost, as the average tests for the two years that the work has been in progress show that the specifications have been on an average exceeded by more than 50 per cent., and that in point of fact, with a cement not a Portland, and which is produced by the intermixture of Portland cement and natural cement, results have been achieved which are at long periods almost equivalent to the results obtained by Portland cements.

The results of this work, as well as certain results obtained on the New York Aqueduct, where a similar grade of mixed cement was used, show that the use of mixed cement, composed of Portland and natural cement, is perfectly safe where the cement is used on works not requiring immense immediate strains and not exposed to immediate frost, and that these cements, made of the natural cement rocks of the Lehigh region and a varying percentage of the Portland cement manufactured in the same region, give, at periods of a month and over, in sand mortars, results nearly equivalent to those obtained with mortars made from the imported Portland cements.

ANNUAL REPORT OF THE BOARD OF DIRECTORS.

For the Fiscal Year 1891.

Presented at the Annual Meeting, January 16, 1892.

To the Engineers' Club of Philadelphia:

Gentlemen:—The Board of Directors takes sincere pleasure in reporting, and in congratulating you upon, a very marked increase in the activity and prosperity of our organization. This is evidenced, not only by the much larger attendance at our meetings, but also by the increased interest manifested in the papers and discussions presented, and in the Club life generally.

The most notable feature in the year's history, and one which will, no doubt, prove to have marked a turning-point in the progress of the Club, is the adoption, at the Business Meeting of March 7, by a vote of 108 to 7, of the new Constitution and By-Laws, prepared by a Committee appointed for the purpose; and the most important provision in this document is undoubtedly that by which the Board of Directors and its Committees then became charged with a large share of the duties which previously fell to the lot of the Secretary.

This innovation has affected notably the conduct of the meetings and the publication of the Proceedings, which devolve upon the Committee on Information and Entertainment and upon the Publication Committee respectively.

The setting apart of certain meetings for the consideration of selected subjects, and the advance publication of papers or abstracts in the notices of the meetings, have resulted in the increased attendance and interest already referred to, and it may be mentioned, to the credit of the profession in general and of our own membership in particular, that these features have had a far more marked effect upon our attendance than the providing of lunches after the meetings. This is evidenced by the following statement:

At the thirty-three meetings held in 1890 and 1891 (omitting the two Annual Meetings and the Reception of February 15, 1890), the attendance, as recorded in the minutes, was as follows:

11 meetings at which no lunch was served, and for which papers were not published or abstracted in advance, average attendance	22
15 meetings at which lunch was served, but for which no papers or abstracts were issued in advance, average attendance	30
7 meetings at which lunch was served, and for which papers or abstracts were issued in advance, average attendance	59

The largest attendance at any meeting during the year, was at the meeting of December 5, when about 70 persons were present.

During 1891 the Publication Committee issued four numbers of the Proceedings, viz.:

Volume VII, Number 6, dated May, 1890, issued May, 1891.
Volume VIII, Number 1, dated Jan., 1891, issued July, 1891.
Volume VIII, Number 2, dated Apr., 1891, issued Aug., 1891.
Volume VIII, Number 3, dated July, 1891, issued Sept., 1891.

It was earnestly hoped that Volume VIII, Number 4, dated October, 1891, might be issued before the close of that month, and thus bring our publication up to time, with its quarterly character completely restored. Every effort was made to this end,

and with some prospect of success, but the serious illness of our sole clerk demoralized our forces to such an extent that the number in question was not issued until the first week in the present month. Work upon the following number, Volume IX, Number 1, January 1892, is now being vigorously prosecuted.

Our receipts from advertisements have, during the past eight months, been nearly doubled, and they now approximately cover the cost of publishing the Proceedings, the burden of which is thus lifted from the Club treasury.

The volumes of the Proceedings now consist each of the four quarterly numbers issued under date of one calendar year.

The subscription price of the Proceedings to non-members has been reduced from $5 per volume of five numbers, to $2 per volume of four numbers, in the hope of increasing our subscription list, and it is thought that when time is found to undertake active canvassing, the reduction in price may have this effect.

The Board wishes to express its appreciation of the work of Mr. Trautwine, while a member of the Board, in devoting so much of his time toward bringing the Proceedings up to date, and making them again self-supporting.

The House Committee, also, has been active in the discharge of its functions. A handsome oaken desk, with letter-boxes for officers, committees and members, and a register for visitors, have been placed in the hall, one of the third-story rooms has been fitted up as a card and chess-room, much-needed lights have been placed in the vestibule and front hall, the walls, etc., of the vestibule have been renovated, and the present vestibule door, swinging freely both ways, has been substituted for the former one.

Another feature of the new Constitution is the creation of the office of Treasurer as distinct from that of the Secretary. The former office has been most satisfactorily filled by Mr. T. Carpenter Smith, who, under the direction of the Finance Committee, has entire charge of the pecuniary affairs of the Club.

From his Annual Report, which is presented to you this evening, you learn that although some $2,500 due from delinquent members have been dropped from our apparent assets as uncollectible, the year has witnessed a reduction of over $800 in the Club indebtedness, which at the end of the year 1891 was about $500, and has since been further reduced by about $100.

Mr. John C. Trautwine, Jr., was appointed by the Board to act as Secretary during the unexpired term of Mr. Howard Murphy, whose resignation of the office took effect December 1.

By authority of the Board, a telephone was introduced into the Club House early in December last. It has already proved of very great utility, and it is believed that its value to the Club will greatly increase in the future, as it must serve to bring the members into nearer and more frequent communication with the Club. A stenographer and typewriter has been employed, and the Club correspondence is now handled promptly.

During the year, and since the issuing of the last printed list, dated June, 1890, 47 active and 3 associate members have been admitted, and the resignations of 24 active and 3 associate members have been presented and accepted.

The Board is advised of the loss, by death, of three members during 1891, viz.:

Moncure Robinson, Honorary Member, elected April 6, 1878, died November 10, 1891.

S. Craige McComb, Active Member, elected November 1, 1884, died February 18, 1891.

R. H. Lee, Active Member, elected November 19, 1881, died December 1891.

Our list of Members at the close of 1891 stood as follows:

	RESIDENT.	NON-RESIDENT.	TOTAL.
Honorary		1	1
Active	238	169	407
Associate	11	2	13
Total	249	172	421

Since that date we have learned of the death, by pneumonia, on the 7th inst., of Mr. Edward Nichols, Active Member of the Club, and President of the Brooks Locomotive Works, Dunkirk, New York.

The Committee appointed to raise subscriptions in aid of the Proposed Engineering Headquarters and Engineering Congress at the World's Columbian Exposition in Chicago, in 1893, has received thus far subscriptions amounting to $313.50. The fund is still in the Treasurer's hands, the Committee not deeming it advisable as yet to turn over any portion of this fund to the Executive Committee having in charge the establishment of such Headquarters.

The following papers, etc., have been presented during the year:

Jan. 10.—Annual Address, Professor H. W. Spangler, Retiring President.
Opening Address, Mr. Wilfred Lewis, President-elect.

Jan. 17.—Locomotive Driving Springs, by Mr. George R. Henderson.
A Portable Photometer for Measuring Street Lights and Illumination in General, by Mr. Carl Hering.

Feb. 7.—An Account of a Photographic Survey, by Mr. Charles H. Haupt.
A Boltless Rail-joint, by Mr. J. Bernard Walker.

Feb. 21.—A Lithograph of the Rivermont Bridge at Lynchburg, Virginia, presented by Mr. Percy T. Osborne.
The Action of Sea-water on Steel and Iron, by Mr. Rudolph Hering. (Part I.)

March 7.—Some Notes on Mississippi-River-Discharge Observations, by Mr. John J. Hoopes.
Notes on Street Cleaning in Washington, D. C., by Mr. Conway B. Hunt.
Re-enforcement of Foundation for a Drawbridge Pier, by Mr. Howard Constable.
The Action of Sea-water on Steel and Iron, by Mr. Rudolph Hering. (Part II.)

March 21.—An Iron Sewer Templet, by Mr. Harry B. Hirsh.
Experiments on the Discharge of Steam through Orifices, by Mr. Strickland L. Kneass.

April 4.—Remarks on the Discharge of Steam through Orifices, by Professor H. W. Spangler.
The Engineering Features of the Road Question, by Mr. Thos. G. Janvier.
An Economical Review of the Alabama Coal Fields, by Mr. C. R. Claghorn.

April 18.—Land-locked Navigation from Long Island Sound to the Mississippi River, by Capt. S. C. McCorkle.

May 2.—The Judson Pneumatic System of Street Railways, as Constructed and Operated at Washington, D. C., by Mr. George R. Ide.

May 16.—Rapid Transit in Cities, by Professor H. W. Spangler.

Electric Railways, by Mr. G. Herbert Condict, visitor.

The Relation of Electricity to Rapid Transit in Cities, by Mr. T. Carpenter Smith.

A Plan and Profile of Market Street, Photographs on the Line of the Ninth Avenue Elevated Railway, New York, and a Copy of Specifications and Proposals for an Elevated Railway on Market Street, Philadelphia, presented by Mr. Samuel L. Smedley.

June 6.—Comparative Experiments upon the Strengths of Rail-joints, by Mr. George W. Creighton.

Rupture under Tension Unsymmetically Applied, by Prof. H. W. Spangler.

June 20.—Two New Forms of Rail-joints, by Mr. Charles S. Churchill.

A Method of Testing Steam Gauges, by Prof. H. W. Spangler.

Oct. 3.—Land-locked Navigation from New York City to Charleston, S. C., by Mr. John C. Trautwine, Jr., from data furnished by Captain Spencer C. McCorkle.

Electrical Transmission of Power, by Mr. Saunders Morris.

The Electric Transmission from Lauffen to Frankfort, by Mr. Coleman Sellers.

The Effect of Centrifugal Force on the Power of Driving-ropes, by Mr. Barton H. Coffey.

Oct. 17.—A Description of Tests of Timber under the Auspices of the Department of Agriculture, by Hon. B. E. Fernow, Chief of the Forestry Division.

The Use of Soft Steel in Bridges, by Mr. Frederick H. Lewis.

Nov. 7.—Some Comparisons as to the Relative Values of Solid, Liquid and Gaseous Fuel, by Mr. Max Livingstone.

Street Paving, Its Cost, Character and Construction, by Mr. W. W. Thayer.

Nov. 21.—A Memorial upon the Death of Moncure Robinson, by Committee appointed to prepare same.

Pamphlets on "Roads Improvements" and "The Gospel of Good Roads," presented by Mr. Percy T. Osborne.

An Article on Rubble Stone Pavement, by Mr. J. Francis Le Baron, from the *Florida Times-Union.*

Street Paving, by Mr. Walter Brinton.

A Map of Philadelphia, Showing the Character of the Paving of its Various Streets, exhibited by Prof. L. M. Haupt.

Purchasing Cement for Large Work, by Mr. Robt. W. Lesley.

Dec. 5.—Report of Committee on Land-locked Navigation.

Discussion of Mr. Frederick H. Lewis' Specifications for Bridge Superstructure.

Dec. 5.—Smoke Prevention or Abatement, by Mr. George R. Ide.
Smoke Prevention or Abatement, by an Ex-Member of the House Committee.

Dec. 19.—The Proposed Boulevard for Philadelphia, and its Cost, by Mr. W. W. Thayer.
Tests of Heated and Headed Wrought-iron Bars, by Prof. H. W. Spangler.
The Practical Projection and Construction of Maps, by Mr. Jacques W. Redway.

At the Business Meeting of the Club, held April 18, the Board was instructed to take steps toward its incorporation, and A. J. Rudderow, Esq., Associate Member of the Club, at once kindly drew up a form of Charter, which was signed by the proper officers; but considerable delay was caused by the summer vacation, and certain changes in its provisions were required by the Court. The Charter, as amended, has just received the official signature, and awaits the acceptance of the Club.

With renewed hope in the future of the Club, we confidently relinquish the charge of its affairs in favor of the incoming Board.

By order of the Board of Directors.

JOHN C. TRAUTWINE, Jr.,
Secretary.

ANNUAL REPORT OF THE TREASURER.

January 16, 1892.

To the Members of the Engineers' Club.

Gentlemen:—On assuming control of the accounts of the Engineers' Club, April 1, 1891, the following was found to be about the condition of its financial affairs:

Cash on hand turned over by the ex-treasurer amounted to	$170 63
Statement handed over by ex-treasurer showed various sums due from advertisers, etc., amounting to	753 00
Also dues to be collected from members who were in arrears for various periods from '82 to the present time	4,365 46
Total	$5,289 09

Of the above the dues to be collected from members are taken as resident or non-resident, according to the last address recorded for them.

The $170.63 cash does not include the amount belonging to the "special" fund for the World's Fair, at Chicago, which has been kept as a separate account.

The liabilities of the Club at that time, as far as could be ascertained, amounted to about $4,437.

This amount including the estimated cost of printing five numbers of the "Proceedings" then either in arrears or due in '91.

The Club thus had an apparent balance to its credit of	$851 82
Of the above amount all but $168 of the advertising accounts have been collected, of which $122 is probably good, as the parties promise payment at an early date, only $46 being written off as "uncollectible"	707 00

Of the amounts due from members, $2,282.76 was from members whose names should have been stricken from the rolls at the end of '90, since they were in arrears and had been in arrears for many years, some not even having paid their initiation fee. This amount has proved to be absolutely uncollectible, and the names of the 70 members have accordingly been stricken from the rolls. Two members of this number, however, claim, and have good evidence in support of their claim, that they had resigned from membership when in good standing, or have expressed a willingness to pay dues up to the time when they should have been dropped, and the Board has decided that they are eligible for readmission to the Club on payment of another initiation fee.

There was, therefore, really due the Club at that time from members in good standing	$2,082 70
Cash	170 63
Crediting the Club also with the amount of advertising which the "Proceedings" had averaged up to that time at $1,000 for the five numbers due	1,000 00
And we fiud the total assets of	$3,960 33

It will thus be seen that instead of having a balance to our credit at that time of $851.82, we really had a deficit of $476.67.

In addition to the above, 17 members, whose arrears of dues amount to $274, have been dropped from the rolls under the By-laws, at the end of '91, for being two years in arrears, and this has made a total reduction in our apparent membership of 87 members, and in assets of $750.67.

We have taken in since April 1, 40 new members and 2 new associate members, whose initiation fees and dues are all paid with the exception of two or three, and amount to $550.

In addition to the other assets of the Club, a "special" fund was started by a few of the members for the purpose of reducing the general debt, and the Club enters upon the year '92 with the following statement:

Total assets either in cash or good accounts receivable	$1,662 00
Total present liabilities, including salaries unpaid, loans and bills at present contracted for as far as known	2,170 56
This leaves us a debt of	$508 56

But we trust that the new membership will easily accomplish the wiping out of this debt, and that by strictly keeping to the rule of dropping members from the list as soon as they are in arrears to a certain amount, we shall not deceive ourselves with the false show of prosperity which has led us to expend money which otherwise we should not have done.

T. Carpenter Smith,
Treasurer.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

From September to December, 1891.

SEPTEMBER 19, 1891. — Present: President Wilfred Lewis, Vice-President David Townsend, and Messrs. Spangler and Trautwine, of the Board, also the Treasurer and the Secretary.

No quorum.

OCTOBER 17, 1891, 4.30 P.M.—Present: President Wilfred Lewis, Messrs. Spangler, Trautwine and Webster, of the Board, and the Secretary.

No quorum.

10.30 P.M.—Present: President Wilfred Lewis, and Messrs. F. H. Lewis, Spangler, Trautwine and Webster, of the Board, also Mr. T. Carpenter Smith, Treasurer and Secretary.

On motion of Professor Spangler, a number of resignations from membership, which had been withheld from presentation in the hope of securing their withdrawal, were referred to the Committee on Membership.

The Publication Committee presented a Report of the Condition of Proceedings, and inclosed two forms of circular-letters sent out with copies of the Proceedings to members who had not paid their dues. The report was received and filed.

It was ordered that permission be granted to the Philadelphia Publishing Company to issue a list of our members in connection with certain advertisements.

The Secretary was authorized to furnish visitors' cards to members of the Club.

The President presented a communication from the Secretary, stating that he would not be a candidate for the office at the next election, and it was ordered that this communication be acknowledged by the Board, the form of acknowledgment to be decided upon by the Publication Committee.

NOVEMBER 14, 1891.—Present: President Wilfred Lewis, and Messrs. F. H. Lewis, Spangler and Trautwine, of the Board, and the Secretary.

It was ordered that the portrait of Moncure Robinson, Honorary Member of the Club, deceased, be draped in mourning, and that the matter of the publication of his phototype be referred to the Publication Committee with power to act.

A committee, composed of Messrs. T. M. Cleemann, chairman, Chas. W. Buchholz and R. B. Osborne, was appointed to prepare a suitable memorial.

NOVEMBER 21, 1891.—Present: President Wilfred Lewis, Vice-President David Townsend, and Messrs. Hering, F. H. Lewis, Spangler and Trautwine, of the Board, also the Treasurer and the Secretary.

The Treasurer made his stated report upon the financial condition of the Club.

Arrangements were made for communicating with such members in arrears as it was thought might still be induced to pay their dues and retain their membership.

A report from the Membership Committee was read.

Mr. Trautwine moved that the time of holding the Board meetings be made 7 P.M., to adjourn at 7.50 P.M., and to reassemble after the Club meeting if necessary. No action was taken on the motion.

10.30 P.M.—Present: President Wilfred Lewis, Vice-President David Townsend, and Messrs. Hering, F. H. Lewis, Townsend and Webster, of the Board.

The following resolution was unanimously adopted: Recognizing that much of the growth of the Club during the past ten years has been due to the energy of the Secretary, the Board desires to record its appreciation of the good services of Mr. Howard Murphy, and its regret that the necessity has arisen for his resignation of that office.

Mr. John C. Trautwine, Jr., was appointed to act as Secretary during the unexpired term of Mr. Howard Murphy, resigned. In accepting this appointment, Mr. Trautwine resigned from the Board of Directors, the resignation to take effect December 1. The resignation was accepted.

Mr. M. Richards Mucklé, Jr., was unanimously elected a member of the Board of Directors, in place of Mr. Trautwine, resigned.

The House Committee was authorized to place Frank R. Coleman, the janitor, in a hospital, and to guarantee his expenses there to an amount not to exceed $50.

NOVEMBER 28, 1891.—Present: President Wilfred Lewis, Messrs. F. H. Lewis, Spangler and Trautwine, of the Board, and the Treasurer.

No quorum.

The members present decided that it would be well to authorize the Secretary to purchase for the Club a typewriting machine, and to arrange for the introduction of a telephone.

DECEMBER 5, 1891.—Present: President Wilfred Lewis, Vice-Presidents S. H. Chauvent and David Townsend, and Messrs. F. H. Lewis, Mucklé, Spangler, of the Board, also the Treasurer and the Secretary.

Action was taken with regard to the status of certain members in arrears for dues.

The matter of issuing a calendar to members was referred to the Publication Committee with power to act.

The Secretary was instructed to transmit to the Club, over the signatures of the President and of the Vice-Presidents, a letter nominating Mr. John C. Trautwine, Jr., for Secretary for 1892, and Mr. T. Carpenter Smith for Treasurer.

The House Committee was authorized to fit up the back third-story room of the main building as a card and chess-room.

DECEMBER 19, 1891.—Present: President Wilfred Lewis, Vice-President David Townsend, and Messrs. F. H. Lewis and Mucklé, of the Board and the Secretary.

Messrs. Arthur Falkenau, G. T. Gwilliam and W. B. Riegner were appointed Tellers to serve at all elections in 1892, with Messrs. B. H. Coffey, Edward Hurst Brown and Lino F. Rondinella as alternates.

Messrs. John L. Gill, Jr., W. W. Thayer and Henry G. Morris were appointed Auditors to examine the accounts of the Treasurer, with Messrs. H. C. Lüders and A. E. Lehman as alternates.

The Secretary's salary for 1892 was fixed at $50 per month, and the Treasurer's salary at $10 per month.

By order of the Board of Directors.

JOHN C. TRAUTWINE, JR., *Secretary.*

GEOLOGICAL SURVEY OF PA
ROOM 18, 4TH FLOOR
POST OFFICE BUILDING
PHILADELPHIA.

PROCEEDINGS

OF THE

ENGINEERS' CLUB OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. IX.] JULY, 1892. [No. 3.

THE COST OF POWER.

XI.

COST OF PRODUCING POWER IN THE INTERNAL COMBUSTION ENGINE.

By BARTON H. COFFEY, Active Member of the Club.

Read March 5, 1892.

THE cost of power production is a problem involving so many variables, that a general solution for all cases, places and conditions is practically impossible. The constants of the equations can, however, be so collected and arranged as to make the solution of a particular case, when certain necessary conditions are given, a comparatively easy task. I will endeavor to follow this method, reducing all quantities to the basis of the horse-power hour.

Unlike the steam-engine, where the heat generator and the heat transformer are two separate and distinct systems, each with its own functions and efficiency, the internal combustion engine contains all the organs necessary to its operation within itself. The complete heat cycle begins at the inlet valve of the engine, and ends at the exhaust. This fact greatly simplifies the treatment of the subject as applied to this type of machine; for we have but to determine the absolute efficiency or ratio of the heat equivalent of the I. H. P. to the total heat supplied the cylinders,

to calculate the heat required for a given I. H. P., and, knowing the value of this heat, the fuel cost is fixed. The remaining charges will be for attendance, maintenance, depreciation and interest on the investment.

I will endeavor to treat of these various elements individually.

Absolute Efficiency.—The absolute efficiency depends principally on the cycle employed, and the diameter of the cylinder.

As the only cycle in extensive use to-day is that of Beau de Rochas, commonly known as the Otto, I will confine myself to it.

In this cycle the efficiency is also greatly affected by the amount of compression. In practice, 45 pounds absolute is the usual figure. The absolute efficiency, I find, can be expressed quite accurately in the form $E = .61 \sqrt{\text{cylinder diameter.}}$ Increasing the size of the cylinder has a marked influence on the jacket loss, hence the increased efficiency.

In Dr. Slaty's test of a 4 horse-power Otto engine, with a 7″ cylinder, the heat carried off by the cooling water amounted to 51 per cent. of the total supplied. The Society of Arts' trials show for a $9\frac{1}{2}$″ Otto cylinder a loss of but 43.2 per cent. This effect is, of course, brought about by the increased ratio of the cylinder volume to its cool periphery.

The efficiency for various sizes of cylinders will be found in Table I. The values are calculated by the approximate empirical formulæ above mentioned, and will be found sufficiently accurate for a power estimate.

Heat Costs.—Under this head I have treated of the three forms of fuel adapted to the internal combustion engine—illuminating gas, producer gas and petroleum. The costs have been reduced to the value of a thermal equivalent of a horse-power for one hour, for the particular fuel chosen.

Illuminating Gas.—The price of illuminating gas in the United States ranges from $1.00 to $1.50 per 1,000 cu. ft. In some localities, I am informed, a discount from standard prices, as high as 30 per cent., is allowed to those using gas for heat or power. In calculating the cost, I have taken 650 B. T. U. as an average calorific value per cu. ft.

The thermal equivalent of a horse-power (for one hour) is 2,565 B. T. U., and on the above basis is worth .395 × cost per

1,000 cu. ft. Table II gives the value in cents for various prices per 1,000 ft.

Producer Gas.—This substance, more properly called semi-water-gas, and popularly known as Dowson Gas, is manufactured by forcing air and steam through a bed of incandescent anthracite or coke. The steam is dissociated, the H passing free into the product, the O together with that of the air uniting with an atom of C to form CO. A gas is thus produced having from 40 to 45 per cent. combustible matter in the form of a mechanical mixture of H and CO, the balance being N with a little CO_2. This gas has volume for volume only from one-fifth to one-fourth the heating power of coal gas. I have taken a cu. ft. as averaging 162 B. T. U. and a pound of coal to 75 cu. ft. of gas.

The price of anthracite varies from $3 to $8 per ton.

The thermal equivalent will then cost .0105 × cost of coal per ton. Table III contains these values tabulated.

Petroleum.—Oils of almost all grades, except the very impure crudes, can be used with success in the internal combustion engine. There appear to be three general methods of procedure in realizing the heat of combustion; these may be termed vaporizing, gasifying and direct combustion.

The Priestman oil-engine is an example of the first type. The oil is heated and sprayed into the cylinder in a vaporous state. It is then compressed and exploded as in the Otto cycle.

The Capitaine motor is an example of the second type, in which the oil is passed through a hot tube, where it is gasified, then into the cylinder, where it is put through the Otto cycle.

In the third type the oil is directly injected into a mass of highly heated and compressed air, where it spontaneously explodes with perfect combustion. Taking a heavy oil of 8 specific gravity and 460° F. boiling point, the total heat per pound equals 21,738 B. T. U. The price of this oil varies, I am told, from 3 to 4½ cents. per gal. The thermal equivalent of a horse-power will then be worth .0176 × cost of oil per gal. Table IV expresses the values.

Cooling Water.—All internal combustion engines up to date, with few exceptions, have been water-jacketed for the twofold purpose of keeping the cylinder walls cool enough to permit lubrication and to prevent premature ignitions.

The amount of heat to be carried off compared with the steam-engine is small, varying from 35 to 50 per cent. of the total heat supplied, while in the best forms of condensing engines it will run from 75 to 80 per cent., the smaller figure being for steam-jacketed cylinders.

Ten square feet of air surface per horse-power will keep the temperature of the cooling water sufficiently low for efficient working. So in cases where water would be an item of expense, the same cooling water could be used continuously. The water cost, being therefore not a necessity, will not be considered in the expense account.

Attendance.—The presence or quality of the attendance is, of course, optional with the owner of the plant. The consideration of its cost in an estimate is, therefore, a matter of judgment.

Engines using city gas or oil require practically no attendance beyond starting and stopping and occasional oiling.

Engines using producer gas will require continuous attendance. Skilled labor is not required, so I think $2 per day will cover it. This for a nine-hour day is a rate of 22.2 cents per hour, from which it is easy to get the horse-power hour rate.

Maintenance. — This includes lubrication, waste, ignition tubes, etc. It may be lumped at .05 cents per horse-power per hour.

Depreciation and Interest.—This item is based on 300 working days per year of nine hours each. An average cost per horse-power of $70 and a depreciation of 10 per cent.

The producer is taken at $10 per horse-power for same conditions. This amounts for the engine to .4 cents per horse-power per hour* and for the producer to .04 cents per horse-power per hour. The constants of the problem are now all tabulated, and to determine the power cost for a particular case is a very simple matter. After deciding on the proper efficiency, divide the fuel factor by it for the fuel cost. Divide the attendance factor by the required horse-power for the attendance cost. The sum of these, together with the maintenance and interest charges, will give the complete cost per horse-power per hour.

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* For engines under ten horse-power increase this figure 50 per cent.

Before taking leave of this subject I would like, in the language of the patent attorneys, to say a few words as to the present state of the art. To begin with, I must mention its chief rival—the steam-engine. It is questionable if the combined efficiency of the best types of steam-engine and boiler ever rises much above 12 per cent. By this I mean what I call a complete steam system, including feed-water heaters, economizers, surface condensers, steam jackets, disengaging valve gear and multiple expansion. From this figure as a maximum it ranges all the way down to 1 per cent., depending on the completeness of the steam system and the quality of the design and workmanship

The report of a test just announced by Mr. Dowson, of England, on a 170 horse-power *Crossley* gas-engine, using producer-gas, shows a consumption of but .85 pounds of coal per horse-power per hour, or an absolute combined efficiency of 21.3 per cent. for the engine and producer. The efficiency of the engine alone is in the neighborhood of 25 per cent., there being a 15 per cent. loss in the producer.

This is a truly astonishing result, and may appear incredible to the steam engineer, but to one familiar with the theory and history of the internal combustion engine, it was to be expected. Mechanically, the gas-engine is as yet inferior to the steam-engine; it cannot be reversed; its mode of governing is faulty, and its power capacity—weight for weight—is less than the steam-engine. But these faults are not inherent, and can all be remedied by ingenuity and study, as was one of the chief former difficulties, namely, starting. The Lanchester self-starter, a recent English invention, appears to me to have completely overcome this trouble, and its principle is as beautifully simple as it is truly scientific.

The steam-engine has about reached its theoretical efficiency limit; it is possible, theoretically, to double the efficiencies already attained for the gas-engine.

The three chief losses—incomplete expansion, conduction to the jacket, and sensible heat of exhaust—are all within the engineer's possible control, and I have no doubt in time will be.

Since the Otto patents expired, the interest in this prime

mover has become much more general, and we already begin to see the effects abroad and in this country.

The almost prohibitive prices at which these machines have hitherto been held, will be reduced, and hence a more general introduction will follow.

The field is bright and promising, and with the encouragement offered by the English successes, I have no doubt Yankee ingenuity and enterprise will not be found lagging, and the United States may have the proud honor of again astonishing Europe with a gas-engine Corliss.

TABLE I.

Gas-Engine Absolute Efficiencies.

Diam. of Cylinder	4″	5″	6″	7″	8″	8½″	9″	9½″	10″	12″	14″	16″	18″
I. H. P.	2	3½	4¼	6¾	10	12¼	15	17	20	35	55	80	110
Efficiency . . .	12.2	13.6	15.0	16.2	17.3	17.8	18.3	18.8	19.3	21.1	22 8	24.4	25.9

TABLE II.

Cost per Thermal H. P. from Illuminating Gas.

Price gas per 1,000 ft.	$0.75	$0.80	$0.90	$1.00	$1.25	$1.50	$1.75	$2.00
Cost T. E. H. P. . .	.296	.316	.356	.395	.494	.592	.691	.790

TABLE III.

Cost per Thermal H. P. from Producer Gas.

Price coal per ton .	$3.00	$3.50	$4.00	$4.50	$5.00	$5.50	$6.00	$7.00	$8.00
Cost T. E. H. P. .	.031	.035	.042	.045	.053	.055	.063	.074	.084

TABLE IV.

Cost per Thermal H. P. from Petroleum.

Price oil per gal.	2½c.	2¾c.	3c.	3½c.	4c.	4½c.	5c.
Cost T. E. H. P.	.044	.048	.053	.062	.070	.079	.088

DISCUSSION.

Mr. Carl Hering stated that the cost of power at any place may also depend on the cost of transmitting it to that place from some other where power is cheap. In many places it may cost less to bring the power from some other place than to generate it at the place of consumption. In this connection he gave some items of cost of the transmission of power from Niagara Falls to Buffalo. The units intended to be used are 5,000 horse-power. The dynamos are to be coupled directly to the turbine by vertical shafts. 600 to 700 volts at the dynamo is to be transformed to 25,000 volts on the line. Three phase dynamos are to be used, making 250 revolutions and supplying 2,000 amperes in each of the three circuits. According to one of the bids received from a Swiss company (Oerlikon Co. of Zurich), the cost of the whole electrical plant per unit of 5,000 horse-power is to be $180,000, or $36 per horse-power. This estimate includes the electrical generator, line and transformers at each end; line cost alone being $20,000. The usual cost of dynamos in this country varies from $50 to $75 per horse-power. The total efficiency of the plant is to be 84 per cent. from the shaft of the turbine to the secondary terminals at Buffalo, the dynamo alone having an efficiency of 96 per cent. The large tunnel is merely a tail-race. Its great length (over a mile) is due to the geographical conditions; also in order to gain the fall of the rapids above the Falls. The turbine shafts have a 120-foot head and the water is led up from below so as to balance the enormous weight of the vertical driving shaft, the turbine and the dynamo armature.

Mr. Wilfred Lewis introduced Mr. J. Bogart, Engineer of the Niagara Falls Construction Company, who stated that the Oerlikon Company's bid is as Mr. Hering has given it; but the problem that interests them is rather what would steam-power cost there under the most favorable conditions, with coal of a given price, or for how much could a company put in a steam plant and sell power to customers? He also stated that he had received two estimates as to the cost of power under these conditions; and that the problem is by no means an easy one is shown by the fact that the larger of these estimates is about two and

one-half times the smaller. The solution must not be complicated by other questions, such as the use of steam for heating or other purposes, and this makes it a particularly difficult one to handle.

Mr. Murphy stated that his recollection was that the cost of pumping water at the eight steam stations in Philadelphia was in the neighborhood of $8 per million gallons, pumped 100 feet, while at Fairmount the cost was $2.

Mr. Smith:—The marine engine seems to be about the nearest to the solution of the problem.

Mr. Hering:—I would like to ask Mr. Bogart what the cost of the water-power will be at Niagara.

Mr. Bogart:—We cannot tell, because the work is not done. The tunnel must be lined with brick and the shafts for the turbine are not finished. We propose making one large shaft instead of several smaller ones for our turbines. We are ready to sell power in large quantities at $10 per horse-power per annum at Niagara.

Mr. Salom:—At Lockport, Mr. E. H. Cowles told me that their power did not cost $3 per annum, and I would like to ask Mr. Bogart what they propose to do with the power that they develop, as five persons per horse-power is about the maximum in the most thickly-settled manufacturing districts.

Mr. Bogart:—The plant, as now under way, is capable of developing 100,000 horse-power. It is proposed to use this first at Niagara Falls, or at the present station, by giving power to manufacturers for coming there. Many manufacturing industries take much more horse-power than that stated by Mr. Salom—wood-pulp mills, for instance—and a 3,000 horse-power plant is being put in by one company, and a second plant is under consideration. It is in the minds of the Company, also, to transmit power to Buffalo, which is a city of a large number of small power establishments. The turbines are to be about 120 feet below the surface, leaving 20 feet to spare. The water that can be taken by the tunnel will take a film of $1\frac{3}{4}$ inches off the Falls, the average depth being about 6 feet, as near as we can judge.

Dr. Chance:—Has any arrangement been made to put in impact wheels?

Mr. Bogart:—Careful study has been made of this subject with the Pelton Company, but the conditions do not seem to be favorable.

Mr. Lesley:—The great importance of the water-power at Niagara Falls seems to lie in its influence upon the city of Buffalo. That city stands at one end of the Lake navigation in the United States, and by reason of that fact is to-day one of the greatest inland shipping ports in the world. It has every element in it to make it a great city, and when you add to its enormous advantages in freights, it should grow to be one of the largest manufacturing centres in the country. In that city is gathered the great bulk of the empty grain cars that have brought grain East, as well as the empty vessels that have brought their cargoes to its wharves and have to return light bound to the West. From these two reasons Buffalo has always had cheap freights, and its manufactures had advantages in all the Western markets. If you add to these cheap power, Buffalo should grow to a great manufacturing center.

Mr. Bogart:—The Company has bought the right of way for another tunnel of the same size.

Mr. Roney:—I should like to ask Mr. Bogart as to the probabilities of trouble from ice.

Mr. Bogart:—We do not anticipate any trouble in the tunnel, and any ice that may form above will be carried down independently in a shaft put in purposely for an ice-shaft.

Mr. Salom:—I have no fear but that there will be users for the power. It requires 24 horse-power per day to produce one pound of aluminum, and a few tons will utilize the entire plant as at present under way.

Mr. Murphy:—Will Mr. Bogart give us an idea of a section of the tunnel?

Mr. Bogart:—The area is that of a circle of 25 feet in diameter. It has, however, a circular top and a very shallow invert. It is through rock and lined with brick masonry.

DISCUSSION.

By Mr. Paul A. N. Winand.

March 19, 1892.

The problem of determining the cost of power for different kinds of motors can be solved, in a general and theoretical way, by considering an ideal case, in which only the cost of the motive agent, the maximum of attendance, the interest on the investment and the usual amount of wear and tear are involved.

When, in some concrete case, however, the choice of a motor has to be decided upon, there are often special conditions which may complicate the question, and which may affect the result considerably. Subsequent or simultaneous use of the motive agent for other purposes, the possibility of combining the attendance with the other work, the amount of space required, and, in some cases, the returns from the sale of by-products, may thus play a more or less important rôle. There are, besides, some other considerations, such as peculiarities of location, fire-risks and others, and convenience for special requirements which may cause one or the other kind of motive power to appear more desirable, and may thus influence the decision independently of the item of cost proper.

When comparing appliances, as different as water motors, steam-engines, electric motors and internal combustion engines, it would certainly not do to omit these incidental considerations.

In the following lines only a few hints in regard to these considerations will be given, more especially concerning the internal combustion engine, together with some data as to the cost of fuel required in actual practice by engines of that class.

Gas- and oil-engines are more directly in competition with the steam-engines because, like these, they can be operated independently of external circumstances, while water- and wind-power are available only when special conditions are fulfilled, and electric motors are simply a means of transmitting power.

The cost of attendance for internal combustion engines is small. It is not greater than for electric motors or for the steam-engine *proper*, *i. e.*, *exclusive* of the boiler. It can, therefore, be omitted from the comparison, if in figuring out the cost of steam-

power, a proper amount is allowed for the attendance required in the production of steam, which (as the boiler, unlike the engine, is not automatic) requires constant attention.

The cost of lubrication in most gas-engines built at present is not more than in steam-engines, and may, therefore, also be omitted.

The amount of coal consumed in steam-engines per indicated horse-power hour (I. H. H.) varies considerably according to the size and kind of the engine.

In tests made on new engines and under the most favorable conditions, good results have been obtained even with engines of moderate size. In practice, however, after being for some time in service, the consumption of fuel is very likely to be found considerably larger than might be expected from the original result, because the valves and piston may be leaky, while apparently the engine is performing its work well. So, also, the boiler may be operated wastefully and the fact not be discoverable without a careful investigation, which is seldom performed. The economical firing of the boiler depends constantly, to a great extent, upon the skill and attention of the man in charge. The result obtained is, therefore, dependent upon a rather uncertain factor.

"In 1885 the Corporation of Birmingham, England, had tests made on six non-condensing steam-engines, taken indiscriminately from among users of power, and ranging from 5 H. P. to 30 H. P. nominal (about 10 to 60 indicated), and found that the consumption in one instance was as high as 27.5 pounds of coal, while it never fell below 9.6 and the average of the whole was 18.1 pounds per I. H. H. Other tests of a large number of steam-engines under 20 H. P. give an average of 11 pounds." *

The engines referred to were certainly not in good condition, but the results stated above are a fair illustration of the discrepancy that should be expected between the coal consumption in actual practice and the efficiency obtained when in the original condition.

In the internal combustion engine such waste of fuel is practically impossible, for it is very difficult to run such an engine, if

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* *Cf.*, W. Robinson: Gas and Petroleum Engines, page 2.

say, 50 per cent. more fuel is admitted than the allowance required by the proper adjustment.

A want of proper adjustment in the amount of fuel admitted, and defects in the working of the valves show themselves in a very apparent manner, thus attracting the user's attention, and can be remedied with a moderate amount of care. It is easy to ascertain, while running, whether every charge taken is ignited.

For these reasons the consumption of fuel in a gas-engine will, in the long run, be generally much nearer the best possible result than with a steam-engine.

The guarantees of the makers and most of the published records of tests refer, of course, to new engines; but the user of power is more interested in the results obtained in the long run, and for him, therefore, the figures of test and guarantees, based upon new engines, do not represent the real proportion of economy.

In the very careful engine trials of the Society of Arts, in 1889, it was found that a gas-engine of about 10 H. P. could be run with 22.6 cubic feet per brake horse-power per hour (B. H. H.), or 19.2 cubic feet per I. H. H.

Even better results than this have been obtained. It is safe to assume that in actual practice a good gas-engine of moderate size (about 10 H. P.) will take per I. H. H., at full power, 22 cubic feet of illuminating gas.

Such gas generally costs $1 to $1.50 per 1,000 cubic feet. The cost for fuel is accordingly 2.2 to 3.3 cents per I. H. H.

This is equivalent in cost to 13 to 19 pounds of coal, costing $3.50 per ton of 2,000 pounds.

It could hardly be claimed that this is a saving in cost of fuel as compared with a steam-engine of that power. Gas-engines are, nevertheless, used quite extensively on account of the saving of a fireman or engineer's wages, as well as in consequence of their greater convenience. This is especially the case when the power is wanted intermittently.

When a gas-engine is used for driving an incandescent light plant of say one hundred 16 C. P. lights, 220 cubic feet per hour will be consumed for producing 1,600 C. P.

The same amount of gas, burned per hour in the usual way, will generally not yield more than 900 C. P. It will accordingly

pay to use gas in this indirect way for lighting whenever the interest on the cost of the plant is divided by a sufficient number of lamp hours per year.

A number of gas-light companies which are supplying electric as well as gas-light, have found it economical to use gas-engines as motive power instead of steam, and even to discard the steam-engines in favor of the internal combustion engine.

When *coal gas* is manufactured the returns from the sale of coke and tar have to be considered. In many cases gas-engines can be used without materially increasing the gas-making plant, while the general expenses and cost of distributing the gas to consumers are not affected at all. The cost of the gas at the burner being largely dependent upon the last two items; the cost of gas at the works or at the engines is but a fraction of its selling price.

Thus one gas company in New England has found that by transforming coal and oil into illuminating gas and using the gas in gas-engines, they consume the equivalent (in cost) of 1.8 pounds of coal per hour for each 2,000 C. P. arc-lamp. In that case there were 62 lamps on 11 miles circuit; each lamp taking about $1\frac{1}{4}$ H. P.

Another company, in Wisconsin, which is making coal-gas, had an outlay for fuel of only $5.76 for running sixty-two 2,000 C. P. lamps during one month (October).

This result was obtained after deducting the profits made on the corresponding amount of by-products.

One firm of gas-engine makers of this city has sold during the last three years eight 30 H. P. engines, three 40 H. P., twenty-two 50 H. P. and four 100 H. P., or a total of 1,860 H. P., and these engines are mostly used by gas companies for running dynamos.

Oil or gasoline can be used in internal combustion engines with about the same efficiency as gas. One gallon of oil is equivalent, in heat-units, to about 180 cubic feet of average illuminating gas. According to this $\frac{1}{8}$ gallon is equivalent to 22 cubic feet of gas. This result is also obtained in practice per I. H. H. in an engine of moderate size. Gasoline or oil, suitable for the purpose, can be obtained at from 5 to 10 cents per gallon. The cost for fuel is accordingly 0.6 to 1.25 cents per I. H. H.

This corresponds to 3.5 to 7.5 pounds of coal costing $3.50 per ton.

In this case, as in that of a gas-engine, the attendance is not more than for the steam-engine proper, or exclusive of boiler, and the wages of a fireman are thus saved.

With natural gas at 15 cents per 1,000 cubic feet, as in Pittsburgh, the cost per I. H. H. is 0.24 cents, or equivalent to 1.5 pounds of coal.

Natural gas having greater heating-power than average illuminating gas, only about 16 cubic feet of it are used per I. H. H.

It would require two or three times as much gas for the same power if it were fired under a boiler, on account of the smaller thermo-dynamical efficiency of the steam-engine as compared with the internal combustion motor.

Oil and gasoline engines are not the only internal combustion motors which can be operated independently of a general distribution of fuel in the gaseous form. For several years a simple apparatus, known as the gas-producer, has been applied in combination with gas-engines, and its use is becoming more and more frequent.

In the producer, by simply passing a mixture of air and steam through a bed of the fuel, anthracite coal or coke is entirely converted, without any condensation or waste, into a weak fuel gas, having a non-luminous flame and only about one-quarter of the heating power of illuminating gas. As one pound of coal yields, however, about 85 cubic feet of this gas, its use is very economical for the production of power by means of gas-engines, as well as for various heating purposes.

There is but little heat lost in the production of this gas, as it is made by a continuous process and not by an alternating one, like the various processes used for making the regular water-gas. For the same reason its manufacture can be made almost automatic and requires but little attendance.

Gas-engines of large power have mostly been used in combination with gas-producers.

In a test made in France by Prof. Witz on a 100 horse-power engine, a consumption of 0.935 pounds of coal per I. H. H. was obtained. In a more recent test, made in England on some 170

horse-power double-cylinder engines, it is claimed that the consumption was as low as 0.883 pounds per I. H. H. In engines of smaller size, say 10 horse-power, the coal consumption is larger, ranging from 1 to 1.5 pounds; but this is still a mere fraction of the amount of coal used in a steam-engine of the same power under the most favorable circumstances.

In this case also the gas-engine, as stated in the beginning, keeps nearer to its original economy in the long run. The same is true of the gas-producer, because, as the total amount of fuel is converted into gas, the quality of the gas is the only thing affected by a defective working of the apparatus, and the character of the gas can be readily and very closely ascertained at any time by simply watching the appearance of the flame of the gas.

Two years ago there were in England and Germany 66 users of gas-producer power plants. At the present time they number probably 100 or more of such plants, and one of 300 horse-power was recently started in this country.

A gas-engine and producer plant being more expensive in first cost than an ordinary steam-engine and boiler, this combination has not been much used for small powers, and is not likely to be, except where coal is very expensive.

Producer-gas, like illuminating and natural gas, can be led without condensation and with but very little leakage to any distance, and is therefore far superior to steam for distributing heat and power from one central generating point to the different parts of a large manufacturing establishment, or of a block of buildings. The piping required is cheaper than for the transmission of the same amount of heat and power by means of steam. For general heating, the heating-surface required is smaller than with steam, because the temperatures are higher.

Several manufacturers are using producer-gas for various purposes, for which gas-heating is desirable, but had been but little used on account of the high price of illuminating gas. Producer-gas, supposing coal to cost $3.50 per ton, is equivalent in price and heating power, everything included, to illuminating gas at 15 cents and less per 1,000 cubic feet.

The advantages of gas heating, which have been shown on

such a large scale in this country by the extensive use of natural gas, are in many cases sufficient to make a producer plant a paying investment, independently of the question of power. In view of these facts there is no doubt that when the advantages of producer-gas for power and for heating are more widely known and understood, the prediction made by Sir Frederick Bramwell, in 1881, before the British Association at York as to the future application of this system, will gradually approach its fulfillment.

XII.

THE COST OF POWER IN MEXICO AND OUR WESTERN MINING REGIONS.

By A. Falkenau, Active Member of the Club.

Read March 19, 1892.

The question of the ultimate cost of power is one that involves so many different items, that in any given problem, unless the engineer considers all of them (and many may appear as outside the pale of engineering proper), he may be led into serious errors. I was never more thoroughly impressed with this fact than when in 1885 I was sent by the Dickson Manufacturing Company to the Rocky Mountain mining regions and Old Mexico, my special mission being to report upon the possibility and desirability of opening up a trade in Mexico for mining machinery. I first went to the mining regions of Colorado and New Mexico, examined into the methods of reducing and treating ores, of applying power, etc., and discussed the particular issue with prominent mining engineers who had been in Mexico and were supposed to know something of the needs of the country. With few exceptions they unhesitatingly stated that there ought to be a large field in Mexico; that if machinery were only more generally introduced the cost of extracting ore and reducing the same would be greatly cheapened. They could not say enough in ridicule of the primitive and absurd methods of the Mexicans, and expressed their contempt for the "greasers," as the Mexicans are abusively called in the West. Later on I found that this feeling of contempt is cordially reciprocated by the Mexicans, who apply to the Americans the euphonious name of "Gringo." The American engineers charged that the only reason preventing the introduction of machinery is the absurd reverence in which the Mexican holds the customs and manners of Montezuma's time, and the obstinate opposition to the introduction of intelligent and improved methods. There is no doubt some foundation for this charge, but upon closer investigation I became convinced

that a great injustice is done the Mexicans. The true key to the cause of their opposition to the introduction of steam-power and improved machinery is to be found only by a careful study of the topography, the natural resources and the political condition of the country.

The cotton and mining industries of Mexico are the principal ones offering opportunity for the use of machinery. There are about ninety cotton mills in the republic, and many of them are provided with the most improved spinning machinery. In fact, outside of the cotton mills there are practically no factories that would be so called from an American standpoint. The mining industry is by far the most important one of Mexico, still the amount of modern machinery used in this branch is practically insignificant. The reason for this marked difference between the branches just mentioned is, that the cotton mills are located near sources of water-power, which are very few and small, and valuable sources like those at Holyoke and Lowell do not exist at all. The obstacles presented by the rugged character of the two countries respectively, to the introduction of machinery in our Western and the Mexican mining regions, are similar and, if anything, by nature greater in the United States. In considering the relative cost of power in the United States and Mexico, I shall confine myself to the mining industries. The Sierra Madres are less precipitous and broken in formation than the Rocky Mountains, and for this reason and also owing to the comparative absence of snow, they present less difficulties in road-making; but, unfortunately, this advantage is entirely annihilated by the utter absence of anything worthy the name of a road. On the other hand, the ever-present snow in the Rockies furnishes a supply of water which, in places, gathers in sufficiently large streams to furnish good water-power. On the northern plateau of Mexico water is so scarce that between Chihuahua and Zacatecas the Mexican Central Railroad finds it necessary to haul water in tank-cars along its road for considerable distances. From these observations it might almost be inferred that there is a far greater growth of timber on the Rockies than on the Sierra Madres. Most mining camps in the Rocky Mountains can obtain all the wood for fuel, as well as for building and for underground

purposes, within a radius of ten miles, and the price for firewood ranges from $3 to $4 a cord. At Zacatecas and Guanajuato, two of the largest mining districts in Mexico, the firewood, such as it is, must be carried by burros from points sixty to eighty miles distant. At Parral, in the southern part of the State of Chihuahua, mesquite and dry oak, used as firewood, costs 75 cent per carga, Mexican money. (A carga is 300 pounds.) This is about equivalent to a price per cord of $10 American money. At Zacatecas, Guanajuato and Pachuca, oak is worth about $13 per cord. Again, the Rocky Mountain region abounds in good coal, which, laid down at the mining towns, costs from $6 to $7 a ton. In Mexico, as far as developments are concerned, there is none whatever. It was reported some years ago that coal had been discovered in Sonora, on the west coast, but it was found only in small, detached deposits, and of such quality as to be commercially valueless. Colonel Dodge, Vice-president of the Mexican National Railroad, informed me that his company had discovered coal north of Monterey, and that as soon as the southern arm of the road had reached Monterey they expected to use coal at an average cost of $4 per ton, causing a considerable reduction in the cost of fuel. At that time, January, 1886, the locomotives were using ocote, a pitchy, yellow pine, which cost, just outside the City of Mexico, $7.50 per cord, but in the city of Mexico, on account of duties and municipal taxes, it cost $14. At Laredo, the northern terminus, and Morelia, the western terminus, the prices ranged from $3 to $4 per cord. English coal is brought to the city of Mexico and Pachuca via the Old Mexican Railroad from Vera Cruz, and costs $20 a ton. The Mexican Central Railroad carries its coal from Southern Colorado. Along the line of the railroad it costs $16.50; at Zacatecas and at Guanajuato, $20. From the railroad stations the coal is transported at considerable cost by mules to the mines, where it is only used for blacksmithing. Laid down at the mines it costs anywhere from $20 to $30 per ton, according to location. Considering, then, the lack of all other natural sources of power, we find the Mexican is almost absolutely dependent on mule- or horse-power and man-power. It is, therefore, important that we consider these sources of energy and their cost. Men do a great

part of the carrying in the cities, and the business of cargador, or carrier, is licensed and regulated in all the larger towns.

As a rule the men, although of medium stature, are remarkably strong. I have seen boys, who could not be more than from fourteen to sixteen years of age, carrying loads of 100 to 150 pounds weight on their backs. For 10 cents they will carry in this way a heavy load a distance of a mile. Wheelbarrows are unknown; hand-barrows, carried by two men, are frequently used. In regard to the wheelbarrow there is a decided prejudice. One mine manager informed me that he had made strenuous efforts to introduce the wheelbarrow, and had a number imported from the United States. I was amused to see that the natives had removed the wheels, converting them into hand-barrows requiring two men. In many of the older mines the ore is still carried up shafts and through tunnels in sacks, supported by a strap about the carrier's head. One item of cost in this method of conveying ore should possibly be considered, namely, the Mexican's piety; for at the exit of the mine is placed an image of the Holy Virgin, and upon each trip, coming and going, he kneels down before it and says his Pater Noster, all the while retaining the load upon his head. For transportation of heavier loads, over long distances, burros are largely used; the load they carry is usually limited to 300 pounds, and machinery must often be designed with this limitation in view. In carrying straw or hay the loads are about 200 pounds. Wagons are but little used. For transportation of passengers, mules and horses attached to heavy stages or horse-cars, were almost exclusively used until 1873. There is a line of horse-cars running from Vera Cruz to Jalapa, a distance of sixty miles. There was also a line running from Irolo to Pachuca, a distance of forty miles, which in 1885 had just been converted into what might be called an apology for a steam railway. In the Haciendas de Beneficio, as the ore reduction works are called, horses and mules are used in large numbers, each machine being driven by the animals exerting their power in the most direct manner. The same is true of the mines. At Zacatecas horses for driving machinery cost about $18 each, and it ordinarily costs from $1.50 to $2 per week for their feed. In 1885 the barley straw

was bad and hay was brought from Kansas, where it cost $5 per ton. By the time it reached Zacatecas, owing to duties, freights and other expenses, it was worth $60 per ton. The Mexicans take good care of the horses that do the heavier work, using them only from two to three hours per day. At the El Rosario mine they had twelve Malacates, or hoisting machines, most of which were only used two or three times per week. Still they kept at least 175 horses for this service. The horses used in the "patios," or yards of the ore reduction works, are poor, broken-down animals and cost from $8 to $12 each. These horses work about six hours per day. Owing to the quicksilver in the pulp, in which they stamp about, they soon become diseased, and therefore the average life of a patio horse is only three to four years. Now, as to labor. The popular American opinion is that the Mexican is invariably lazy. This may be said with some truth of the inhabitants of the tropical regions of Mexico; and who would not feel inclined to take his ease living under a burning sun? In our own Arizona our white Americans sleep or stay in the house until 3 o'clock in the afternoon during the summer months. The managers of mines and Haciendas de Beneficio whom I met invariably spoke well of their employees. Let me give the testimony of Colonel Dodge, of the Mexican National Road. He stated to me that when he built the road the peons in the country through which it passed were receiving 25 cents per day for farm work. As soon as it became known that the railroad offered 37½ cents they came in large numbers and not only worked diligently, but asked to be allowed to work on holidays. At the mines the peons or common laborers receive from 37 to 60 cents per day, the over-ground men receive from 75 cents to $1, and foremen $1.50. Many of the men at the mines and reduction works are paid according to the amount produced, or, where paid by the day, receive about $1. The blacksmith is considered a most valuable man and, therefore, receives $2 per day. There are no native skilled machinists and engineers, and those coming from foreign countries command from $6 to $10 per day. In the Rocky Mountain regions machinists and engineers receive from $4 to $5 per day. In dealing with the political

side of the question we have to consider the duties and other taxes levied on machinery and other articles required in the production and utilization of power. On many articles the duties are exorbitant, but, fortunately, the government has striven to encourage the introduction of mining machinery by admitting the same free of duty. Spinning machinery, when moved by steam, is free, but otherwise has to pay a duty of 5 cents per kilogram, or $10\frac{4}{10}$ cents per pound. Note the exception. The Mexican government evidently recognizes the great cost of introduction and maintenance of steam-power. Coal is admitted free of duty; hardware pays 25 cents per kilogram; tools, 5 cents; wagons, 6 to 50 cents, according to weight and size; and house furniture 40 cents per gross kilogram. It will thus be seen that the cost of man and animal power in Mexico is exceedingly small; that, on the other hand, the cost of a plant of machinery is greatly enhanced owing to the difficulties of transportation, freights, etc., and its maintenance is very expensive, owing to the lack of skilled labor and facilities for making repairs. Above all, the most important fact is clear, that fuel costs from three to four times as much in the Mexican as it does in our western mining regions.

Having now made comparisons of the general items which affect the cost of power in the two countries, let us consider the relative cost of power as applied to two different processes aiming at the same results. To arrive at a just conclusion, we must not only consider the expense incident upon the production of the power, but also the value of the product in the two cases. Viewed from this standpoint I have learned to admire the good judgment of the Mexicans, as shown in the majority of cases that came under my notice, and the intelligent use they made of the crude resources at their command. The ordinary methods of treating silver and gold ores in our country are by the stamp-mill and smelting furnace. In Mexico the principal method in use is what is known as the patio process. In American mills a saving of from 60 to 80 per cent. of precious metals in the ores is considered good work, whereas by the patio process a saving of from 90 to 92 per cent. is claimed as a common performance by a number of well-known mining engineers in charge of

works, whom I met. Mr. Richard E. Chism, of the American Institute of Mining Engineers, in his paper on the patio process in San Dimas, Mexico, rather discredits the process, still he concedes that the saving ranges from 75 to 80 per cent. He states the cost of working the ore in the Hacienda referred to as being $27.58 per ton. Mr. James Wood, the manager of the famous El Botte Mining Company, stated to me that the average cost of treating the ore at his hacienda was $8 to $10 per ton. In the United States the cost of milling free milling ores varies from $5 to $15 per ton, and roasting milling ores from $10 to $25 per ton. Even if there should be a large difference in favor of the United States between the cost of milling there and the patio process in Mexico, it is evidently eliminated, in most cases, by the great cost consequent upon the introduction and maintenance of machinery and a steam-power plant. Again, the product obtained from the mills is from 750 to 920 fine, whereas by the patio process a bar is produced which is 990 to 995 fine. The superiority of the Mexican system in this point Mr. Chism fully admits. I quote from his paper as follows: "An assay of several bars gave an average of $\frac{994}{1000}$ of silver and $\frac{3\frac{1}{4}}{1000}$ of gold, leaving only $\frac{2\frac{3}{4}}{1000}$ for the baser metals, dirt and loss." I fear that his prediction, made in 1882, that probably in a decade or two the patio haciendas now in operation will be memories of the past, will not come true. So much for the results of the two processes, which are largely in favor of the Mexican. Chemically, the milling and patio processes are alike, and the main differences lie in the mechanical manipulation, the application of power and the time consumed. In both processes the ore is first crushed fine, then mixed with quicksilver, which forms an amalgam with the silver; then the whole mass is washed, the amalgam being retained, and finally the amalgam is retorted, the quicksilver being driven off, leaving the silver bullion.

A modern stamp-mill, of any size, is quite an expensive plant, and requires the use of steam for heating purposes, as well as for power. A ten-stamp wet silver mill costs about $10,000 in Chicago, including a 60 horse-power boiler and engine. The machinery consists of a crusher, two feeders, the battery of stamps, two pans, one settler, one agitator and two concentrating

tables. The mill complete requires about 50 horse-power to drive it, and steam is used to heat the amalgamating pans and sometimes also in the crusher.

In the patio process the grinding is done by chilly mills and arrastras, these being driven by horse-power. The amalgamating process is simple, interesting, unique and effective. The powdered ore having been mixed with water, the pulp is spread out about eight inches deep in the patio, which is the Spanish for yard or court; quicksilver is sprayed on the ore, and for from two to six weeks, according to the season of the year, horses are driven through this mud for six hours each day. With their hoofs they stir up the mass, and thus enable thorough amalgamation to take place. The settling or separating of the amalgam is done in shallow stone settling tanks, in which men stamp about. Sometimes large stone tanks with stirring vanes are used, operated by horses. It will be observed that, evidently, the treatment of a given lot of ore will take from three to eight weeks, whereas by the milling process the same can be put through in a day. On the face of it, it would appear that a process which consumed so enormously much more time would be accordingly much more expensive. It must be remembered, however, that the cheap man- and horse-power are used, and, as I have already pointed out, that superior results are obtained. Furthermore, the plant is a cheap one, easily maintained and superintended. Let us attempt to replace it by a modern milling plant. The expenses may at once become greater than the returns, and very often do so, as numerous attempts at placing plants have shown. At the San Raphael Hacienda, at Zacatecas, a stamp-mill had been erected, and after a fair trial it was abandoned and the patio process again adopted. Mr. James Wood, whom I have already mentioned as an English gentleman of extensive experience in the treatment of Mexican ores, informed me that he had made the experiment of crushing his ores by a Blake crusher and rolls run by steam-power, but found that the cost of crushing was twice as great as before, with a chilly mill, and he therefore returned to the latter method. Señor Alcalde, manager of the El Rosario mine of Zacatecas, stated that he had attempted to replace the Malacate with which he hoisted 2,000 pounds

with four horses, in three and a-half to four minutes, a distance of 170 meters, by an American horse whim. This whim had four poles for four horses, but they could not budge the load, and six horses could only work the whim slowly, while with the Malacate the horses were kept on a trot. Although there is undoubtedly a greater loss due to friction in the whim than in the Malacate, it appeared to me that bad alignment must have added to the loss. Prejudice also may have aided in bringing about the result. The Malacate was restored to its former dignity. Probably the most noted case of error in attempting to introduce steam-power, without counting the cost, is that of the Real del Monte mine at Pachuca. The mine by crude labor is said to have yielded four and one-half millions in a single year. An English company placed an extensive pumping and hoisting plant on the property in hope of increasing the net output at that time. The scheme utterly failed, and when the old crude methods were returned to, a paying basis was again reached.

Our Western mining country, too, is full of monuments to mistaken engineering. I have seen many an abandoned mill in the rugged Rockies which no doubt failed because the cost of power was not properly gauged, but more frequently in this country the failures are due to exaggerated expectations as to the yield of the ores in the neighborhood. Between Idaho Springs and Central City can be seen a whole graveyard of such mills, one of them built by Fitz John Porter in 1860. It will be clearly seen that our southern neighbor is not so favored by nature as one would have supposed from Prescott's Romances, and I do not believe that the unfavorable natural conditions can ever be changed. How, then, can the republic solve its problem of cost of power, which so greatly stands in its road to progress? Only by inviting external influences, by obtaining better intercommunication with other countries, and by cheaper coal. Owing to its propinquity and resources, the United States should be the first to accept the invitation. In these days of wonderful achievements, is it too chimerical to anticipate that the time will come when we shall generate power at our coal mines, and from our great concentrated water-powers, and transmit the same along large veins of copper by

the electric fluid, with a network of capillaries extending all over the surface of the Southern Republic? Should this dream be consummated the complete development of Mexico would be assured.

DISCUSSION.

Mr. A. L. Eltonhead: A satisfactory comparison between the United States and Mexico, in the matter of the cost of power, is rendered practically impossible by the radical differences of the conditions prevailing in the two countries. Mexico is far behind us in civilization,* and it will be a score of years before she reaches a condition where her engineering methods will become at all comparable with those now prevailing here.

Modern machinery in Mexico has to face the fact that labor costs but from 12½ to 75 cents of Mexican money per day, and that time-saving is therefore a matter of comparatively small moment to the Mexican. Nevertheless, if it can be shown that machinery will not only hasten but cheapen the work, the Mexicans are not slow to adopt it. The trouble is that they meet with unfortunate experience in making experiments in this direction. Take, for instance, the old "patio" process of treating silver ores. The ores are mixed by the tramping of mules, and the heat employed is that of the sun. The cost is trifling, and it is claimed that 80 to 85 per cent. of the silver is recovered, including what the native peons gather from the waste-dump outside of the mines, before it is washed down stream. The process is hard upon the mules, for they soon lose their hoofs and thus become perfectly useless. An enterprising American, by assuring a mine-owner that his machinery would do the work in one-tenth of the time and save 90 to 95 per cent. of the silver, induced him to try a new process. Unfortunately, the experiment was a failure, and the mine-owner found himself poorer in money but

*There was a time, before the railroads opened up the interior of the country, when Mexican merchants charged more for goods when sold in large amounts than when sold in small quantities, for the reason that if their stock were suddenly reduced by large sales, they were put to considerable extra expense to replenish it.

richer in experience. It is needless to say that such failures as this must act prejudicially against further efforts toward the introduction of machinery. The native indolence of the Mexican also leads him to prefer a simple and inexpensive process which he understands, and which will give him from 80 to 85 per cent. of the metal, to a complicated process involving the use of expensive machinery, even if it gives him 5 or 10 per cent. more of the metal. As already remarked, a mere saving in time is of small consequence to him. He is quite satisfied to turn over his waste-dumps to the stranger, and to let him work them at his own expense for machinery, only to find that it costs more than it comes to.

On sugar plantations in Mexico there is now a ready sale for machinery of improved construction in power and labor-saving appliances, yet as late as 1883 I endeavored to introduce there a patented process for the use of oil or water-gas for fuel for motive power and other purposes. Owing to the great scarcity of fuel in Mexico, and the consequent high price of coal there, I naturally looked upon that country as a good field for the process, believing that the railroads and other steam-users would welcome as a boon my cheap and easily-handled fuel. The Mexican National Railway (narrow-gauge) was then using, on an average, one cord of wood, costing $8.42, for a run of 50.6 kilometers, while two quarts of oil, costing 36 cents, lasted for a run of 68.6 kilometers. Nevertheless, I found it quite impossible to introduce the improved fuel.

The number of kilometers run per month on the various divisions of the road was as follows:

	Kilometers.
Passenger engines . . .	24,250
Freight	26,224
Construction	20,600
Mixed	15,803
Switch	7,815
Total	94,692

The cost per kilometer run averaged:

	Cents.
Repairs, ordinary	0.7
Fuel	16.7
Wages	6.3
Stores	0.9
Total	24.6

or, say, 25 cents per kilometer, or a fraction over 41 cents per mile, for motive power. The Mexican Central (standard gauge), so far as I could learn, cost about the same.

From personal observations in Mexico, covering the country between Vera Cruz and El Paso del Norte, and extending over a residence of four years, I am convinced that, notwithstanding the present cheapness of labor, there is a growing field for the introduction of labor-saving machinery in Mexico; but to develop this field will require the education of the Mexican up to the standard of the United States, and this process will be greatly impeded by unfortunate experiments with unsatisfactory machinery.

XIII.

ERRORS IN THE DESIGN OF PULLEYS AND SHAFTING.

By Alan N. Lukens, Active Member of the Club.

Read March 19, 1892.

In the following paper I propose to notice some of the causes of waste in power transmission by pulleys and leather belting, leaving the amount of loss to be determined in each special case.

A line of shafting is subjected to two strains, viz., a transverse strain, due to the various forces applied perpendicularly to it between the points of support, and the torsional strain, due to the forces turning the shaft by means of the driving pulley.

The transverse strain, due to the weight of the shaft itself and of the pulleys it carries, is increased by the tension of a belt running downward from the shaft and decreased by that of a belt running upward. The resultant transverse strain, due to a combination of the foregoing with those due to horizontal or inclined belts, is to be found by the parallelogram of forces.

It will be seen at a glance that the less transverse strain there is the easier our shaft will turn. To keep the flexure of the shaft down to the minimum it is best to have the hangers so spaced that they will come as near as possible to the pulleys, especially the larger ones; and for the same reason belts pulling off opposite sides of a shaft should be as near as possible to each other. Main driving pulleys should always have a hanger on each side. This practically prevents all flexure of the shaft—a flexure which, when considerable, very quickly tells on the life of the plant.

I have no accurate figures at hand as to the cost of loss of power from this cause; but, perhaps, some of the members can recall something on the subject and present it in the way of discussion.

The torsional or twisting strain on a shaft is greatest near the main driver, and decreases as power is taken off the shaft, becoming zero (except for friction at the bearing) at the end of the shaft. When the shaft is very long and light, the torsional strain is apt to produce a very undesirable jerky motion at its extreme end. This can be reduced by placing the main driver

in the center of the line, thus reducing the strain put upon the shaft. This arrangement allows the use of lighter shafts with a reduction in the first cost.

All possible care should be taken to have the bearings rigid, so that they shall hold the shaft firmly in place. At the same time they must not bind the shaft.

In a small mill in one of our Southern States, where I was at one time engaged, there was a very marked and expensive case of too tight bearings. On taking charge I found that while the boilers were doing exceptionally well, and while the indicator showed the engine to be working to perfection and developing nearly 125 horse-power, there was always a scarcity of steam. I at once ordered an examination, with the result that all bearings in the place, from the head of the main shaft to the smallest journal on the ore concentrator, were found to be so hot that water would boil when thrown on them. After going over all these, putting in liners, repouring, etc. where necessary, until everything worked smoothly, the engine was found to be exerting only 115 horse-power, showing an enormous, almost preposterous, loss through this cause alone.

The fuel used was green pine-wood, and before the overhauling $5\frac{1}{2}$ cords were required for a ten-hour day. After the readjustment the consumption of fuel fell to 5 cords per day. One cord of this kind of wood is equal to about 1,000 pounds of coal, which, at $2.25 per ton, would be $1, so that the daily saving of half a cord resulted in an economy of 50 cents.

Shafting is often very greatly handicapped by the faulty application of the pulleys and belts. The most serious error made in this connection is that of running unreasonably tight belts. It is amazing how much power is wasted in this way, to say nothing of the trouble of broken pulleys, hot boxes, etc. The enormous and absolutely useless pressure thus put upon the pulleys must in time break them, besides wearing out the whole system of shafting and bearings. If manufacturers realized what these ridiculously tight belts cost them in a year they would give vent to some very strong and expressive language. It has been calculated by several eminent engineers that the loss of power, from friction alone, in some of the best-equipped mills in the country, is from 22 to as high as 39 per cent.

It is unreasonable to suppose that the minimum friction would consume this amount of power, and no other cause is so potent in increasing friction as undue tightness of belts, which, when they number by hundreds in a mill, easily account for the great loss of power referred to.

Estimating a horse-power as requiring a consumption of 40 pounds of coal per day of ten hours, and granting that 15 per cent. is a reasonable allowance for loss of power through unavoidable friction, and taking the actual loss of power at 22 per cent. (the lowest of the figures given), we have a balance of 7 per cent. as the actual loss. This would be 2.8 pounds of coal per horse-power per day.

In a plant using 200 horse-power this would mean 560 pounds of coal per day, which, at $2.25 per ton, would cost exactly 65 cents. For three hundred days running in a year this would mean $195, to say nothing of the extra wear on the hangers, the shortening of the life of the belts themselves, and so on.

The point next in importance to the tension of the belts is the arrangement of the pulleys. These should be as large as is consistent with a proper regard for symmetry and proportion; for the larger the diameter of a pulley the less the pull necessary to transmit a given amount of power.

The use of too small pulleys, by increasing the liability to slipping of the belt, is often responsible for the employment of excessive tension in the latter. The following case in point came under my notice: A few feet from the end of a line of shafting, and near the end hanger, was an 18 x 6-inch pulley driving a line of countershafting with a duplicate pulley. Noticing an odor of hot oil about the mill, I made an examination, and found that it came from the end hanger referred to, which was too hot to bear one's hand on. The engine was shut down and a thorough inspection ordered, which brought word to the office that the shaft had worn through the babbitt in the box, and was running on the cast-iron. As this was not a very satisfactory explanation of the trouble, I investigated further and at once saw the real cause. The belt had been slipping badly, and had been taken up. Still it slipped, so another piece was cut out, and so on, until the tension had caused the shaft to cut through the babbitt, and also pulled the hangers on both shafts considerably out of

line. On questioning the man in charge, it was found that this belt had always slipped ever since it was put in, being thus a continual source of trouble, besides wearing out the belt very quickly. A new belt had been put on only three months before and now was entirely useless. The only spare pulleys available were two of 34 inches diameter by 4 inches face, that is, nearly twice the diameter of the former one, and two inches less face. These two pulleys were put on, and an old 4-inch belt used, having the proper tension. This has been doing the work with entire satisfaction ever since, now nearly two years, showing conclusively that the whole trouble came from the use of a small pulley which required an undue tightening of the belt in order to avoid slipping. The distance between centers of these shafts was twenty-two feet, and the cost of a single leather belt of this span, and six inches wide, would be about $19.

The opposite fault, that of too slack belts, is also to be avoided, particularly in long spans, as it will cause flapping and swaying of the belt. A very marked case of this kind came to the writer's notice in this way. A neighboring factory had recently put in a new belt on a span of some forty or fifty feet. The belt stretched so as to sag nearly sixteen inches, and the slack side swayed laterally with an even, regular swing, corresponding with the vibrating length of the building, and imparting its motion to it, so that the whole system of timbers swayed in unison. This would soon have loosened every joint and nail in the building had it been allowed to go on. The remedy which I prescribed was to take up the belt until it sagged only six inches, and then to support both top and bottom sides of the belt with an idler.

To sum up the evils of errors in the design of systems of shafting, we notice, first, errors in the alignment of the shafting and in the spacing of hangers and pulleys; and, second, errors in the adjustment of the bearings, in the size of the pulleys and in the tension of the belts. Lubrication I will leave for others to discuss. All these errors add to the useless expenditure for power, and consume time and labor in keeping things in good order. That "time is money" every one knows.

XIV.

THE PRACTICAL PROJECTION AND CONSTRUCTION OF MAPS.

By Jacques W. Redway, Active Member of the Club.

Read December 19, 1891.

It is the purpose of this monograph to present a few ideas on the subject of map-projection, which the writer believes will be found valuable if the experience of others has been bought as expensively as has been his own. In the various treatises on graphic constructions and perspectives, the subject of the projection of the sphere and the development of the projection upon the cone and the cylinder have been neglected, except so far as the construction of certain formulæ is concerned. In 1882 the United States Coast and Geodetic Survey issued a volume on the mathematical construction of projections (Craig), and in a subsequent report there is found a monograph on the value of the polyconic projection (Schotte), the paper being supplemented by a series of maps illustrating the various projections in common use. These treatises are probably the most exhaustive ever published so far as the deduction of formulæ and the value of coordinates is concerned. The tables for the construction of the polyconic projection are a monument to the skill and faithful labor of the computors. In 1890 the author of this paper published a manual on map-drawing,* designed for teachers. This manual is of the most elementary character and pertains to school and educational maps only. To the surveyor and engineer it has little or no value. In the following pages will be found a discussion of the comparative values of the more common projections and the most practical method of constructing them. For the tables appended the author is indebted to the publications of the United States Coast Survey. Several of the cuts have been loaned by the courtesy of D. C. Heath & Co.

In general, map-projections may be divided into two classes,

* The Reproduction of Geographical Forms. D. C. Heath & Co., Boston.

perspectives and developments. The former are of but little practical use to the engineer or surveyor. They are rarely used except where a map of a hemisphere is required. It is hardly necessary to present the formulæ for the construction of these. Diagrams will answer the purpose much better. Moreover, in practice, it is often found expedient to modify the construction in a consistent but very arbitrary manner, and in such cases a formula would be useless. For instance, the meridians in the various globular projections, the bounding meridian excepted, are semi-ellipses, terminated by and meeting at the extremities of a common major axis. Now, the construction of an ellipse, though easy in theory, is very difficult in practice, especially with the ruling pen. Every draughtsman knows how difficult it is to make a great number of straight lines converge to a point. To construct a number of ellipses, each having its minor axis of correct length, and all tangent internally at the extremities of the common major axis, is an extremely difficult task. Hence it is the common practice to substitute arcs of circles for meridians instead of semi-ellipses. The distortion arising from the modification is very slight and is confined to polar regions where consistency rather than great accuracy is required.

The chief difference between the various globular perspectives depends on the position of the point of sight. The latter may be: (1) without the sphere; (2) on the opposite surface of the sphere; (3) at the center of the sphere. The first may be either the *orthographic* or the *equidistant*, the second is the *stereographic*, the third the *gnomonic* projection. Let us now discuss these seriatim, leaving the equidistant until the last.

The Orthographic Projection.—The orthographic projection is a perspective, pure and simple. The point of sight is most conveniently taken in the plane of the equator, but without the sphere. Now, if any point near the surface of the sphere be taken as a point of sight and tangents be drawn to the sphere, it is evident that the tangents will not include a hemisphere—nothing but parallel lines will do this. But inasmuch as the parallels will never converge, it is evident that the point of sight must be taken at an infinite distance. In this case if the point of sight be in the plane of the equator, it will practically be in the plane of every parallel also.

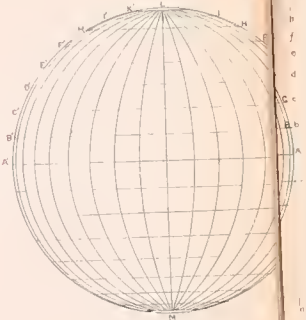


Fig 1.

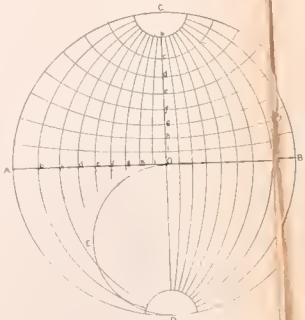


Fig 2.



Fig.3

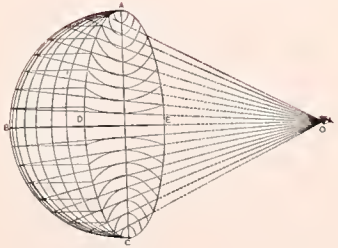


Fig 5

Let *A L A′ M* (Fig. 1) be a section of a sphere passing through the plane of any meridian. Draw the diameters *LM* and *AA′* mutually at right angles. Divide the arc *AL* into any convenient number of parts. If into nine parts, the parallels will have ten-degree distances. In a similar manner divide each quadrant. Now, on the construction line *ln* (which needs not be drawn) *Ab* is evidently the projection of the arcs *AB* and *A′B′*, *cd* of the arcs *CD* and *C′D′*, *de* of the arcs *DE* and *D′E′*, etc. Now, if the vertices of the corresponding arcs in the two quadrants be joined as in the accompanying figure, the lines joining them will be the parallels of the map. In the same manner lay off the projection of each arc in order on the equator and the points thus established will be the points where the meridians intersect the equator.

In this projection the parallels are of necessity straight lines. The meridians theoretically are semi-ellipses; practically it is best to make them arcs of circles. Each meridian must, of course, pass through the poles and its established point of intersection on the equator. The radius for drawing the meridians may be readily established by the well-known theorem of "passing a circumference through any three points not in a straight line." In practice, however, it is easier to establish it by trial.

Maps of hemispheres on the orthographic projection are still occasionally found in school text-books and atlases. Why, it is hard to say. It distorts where distortion should be avoided; it is inartistic; and, in fact, compared with other projections, it has not the first redeeming quality.

The Stereographic Projection.—In the stereographic projection the point of sight is taken at the surface of the sphere—most conveniently at one of the poles. Draw the semi-circumference *O E D* (Fig. 2) and the diameter *O D*. With *O* as a center and a radius *O B*, draw the circumference *A C B D*. Draw the diameter *A B* perpendicular to *C D*. On the supposition that the meridians and parallels are ten degrees apart, divide the quadrants *O E* into nine equal parts. From *D*, through the extremities of these arcs, draw the secants *Da*, *Db*, *Dc*, etc.; or, rather, by means of these guides, locate the points *b*, *c*, *d*, etc.; they are the points where the meridians intersect the equator. Establish

points having equal value of position on *C D*, both above and below the equator, and divide each quadrant of the circumference *A B C D* into nine equal parts. With a radius which may be readily found by trial, and a center on some part of the line *C D* extended, draw arcs of circles, each of which is limited by the proper divisions of *A C* and *C B* and which also passes through its proper point on *C D*. It is hardly necessary to add that the semi-circumference *O E D* and the secants *D C*, etc., are construction lines, and should be drawn as pencil-lines only.

This projection has many advantages and some disadvantages. Among the advantages it may be noted that all circles on the globe are represented by circles on the map. Moreover, the lines that cut one another on the globe cut one another at the same angle on the map, thereby preserving fidelity of outline. Inasmuch as the distance between parallels and meridians increases from the center toward the circumference, however, there is a noticeable distortion, and equality of area is not preserved. This is its chief disadvantage; but inasmuch as the cartographer must always choose between accuracy of area and outline, it is a matter of judgment only which may be the better sacrificed. From an artistic standpoint the stereographic projection cannot be surpassed, and, all other things being equal, this quality may at times have weight. The author selected this as the most suitable projection for the hemispheres in his series of school geographies.

The Gnomonic Projection.—This projection receives its name from the fact that its fundamental principle is similar to that of the gnomon or sun-dial. In this case the point of sight is taken at the center of the sphere. Let *A B C D* (Fig. 3) be the circumference of a circle of any convenient size, and *mn* a limited part of the central meridian tangent at *D*. Divide the quadrant *A B* into any convenient number of parts according to the desired number of parallels. The points where the secants drawn through the extremities of these arcs meet the tangent will be the loci where the meridians cross the equator. If the parallels are projected upon a tangent plane, it is evident that in high latitudes the plane must become infinitely large, inasmuch as the secant of 90° will be parallel to the tangent, and, therefore, will never meet it. Evi-

Globular (Gnomonic) Projection of the Sphere
on a circumscribed Cube
Axis of Contact at Top surface + 30° N
Middle Lines + 100° W of G
(U. S. Coast Survey.)

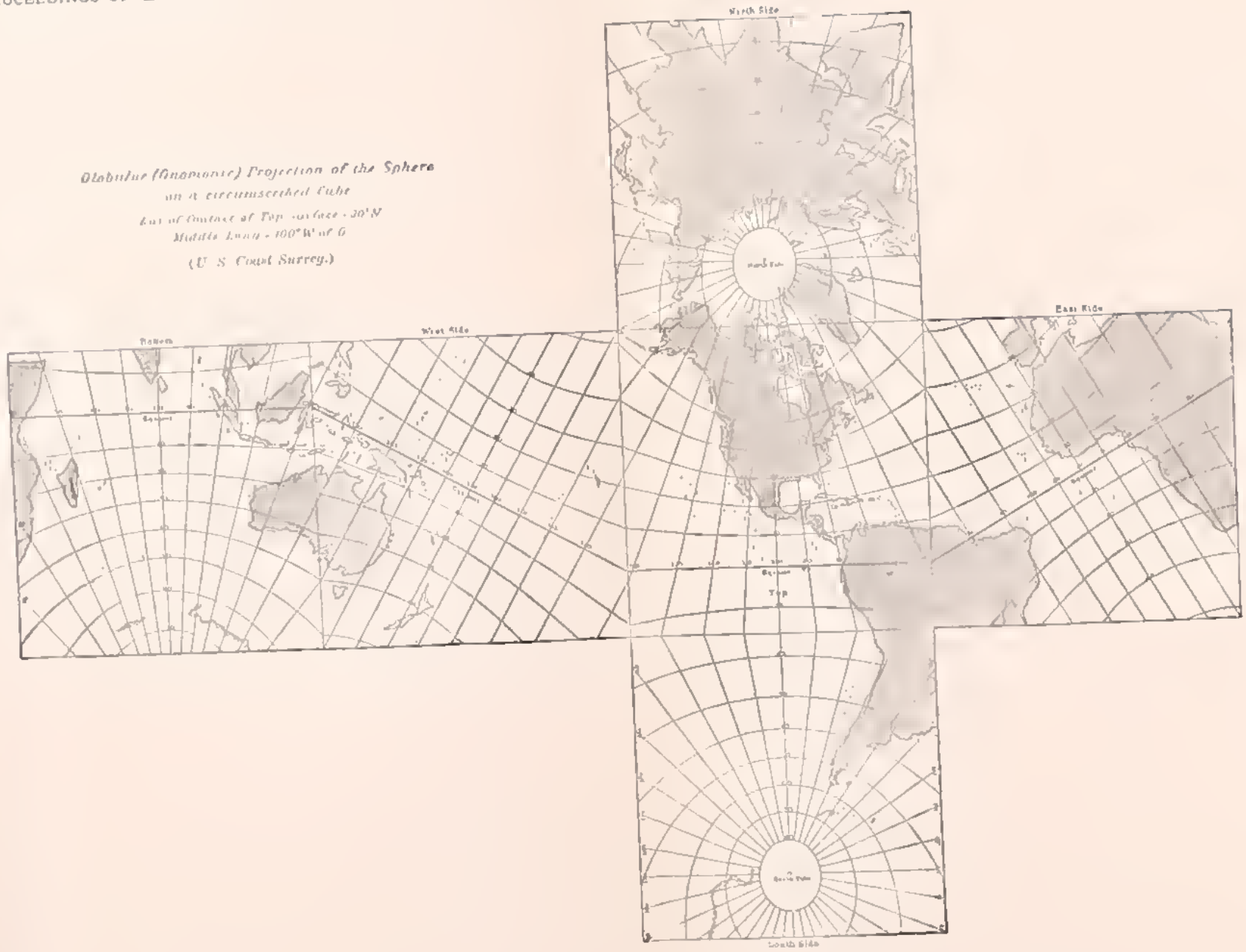


Fig. 4

dently such a projection will be of but little service if made upon a single plane, but if we conceive the parallels and meridians of a sphere projected upon a circumscribed cube, the gnomonic projection becomes a very practical and useful one. With the eye at the center of the sphere, it is evident that the meridians and the equator will be straight lines, while all small circles are practically arcs of ellipses. The accompanying map of the world (Fig. 4) drawn upon this projection, shows how ingeniously it may be adapted to the charting of the grand divisions of land. From the very nature of the case, however, it is much better adapted for star charts than terrestrial maps.

In one respect, however, the gnomonic perspective is noteworthy. The impossibility of extending on a single plane beyond a limited area of which the intersection of the central meridian and the equator is the center, naturally suggests the development of the surface of the sphere upon that of the circumscribed cube. This perspective, therefore, becomes a true projection as the term is used in cartography. It is only a short step from the circumscribed cube to the tangent cylinder and the tangent cone, and the gnomonic projection is the connecting link between the perspectives and the developed projections.

The Globula ror Equidistant Projection.—This, strictly speaking, is neither a perspective nor a true projection, but notwithstanding its illegitimacy, it is one of the most desirable, and certainly the most practical, development of the sphere on a plane. It was planned more than two hundred years ago by de la Hire, and age has not diminished its popularity. Figure 5 will show the theory of its construction. *A B C D E* is a hemisphere, and *A D C E* we may imagine a sheet of semi-transparent paper stretched upon a section. The observer stands in front of the section, the eye being in the plane of the equator. Now the projection of the parallels on the sheet of paper will evidently be a series of curved lines—theoretically ellipses. In this illustration the meridians have been omitted; they are shown, however, in the accompanying diagram. When it is deemed desirable to construct this projection mathematically, the following plan will answer all purposes.

Let *m n* (Fig. 6) be either the equator or the central meridian tan-

gent to the circumference $O\,B\,C\,K$ at B, and therefore perpendicular to $B\,K$. Prolong $B\,K$ so that $K\,P$ is equal to half the chord of a quadrant. P will be the point of sight required. Divide the quadrant $A\,B$ into any required number of parts, and the points where the secants drawn from P through the extremities of these arcs cut $m\,n$ will be the loci at which the respective meridians intersect the equator. The lines Bh, hg, gf, etc., the projections of the arcs BH, HG, GF, etc., differ in length by a small value only. The parallels are ellipses drawn each through the extremities of the proper arcs and the established points of the central meridian.

So much for the theoretical construction. Practically a good working projection can be made in a much simpler way. Draw a diameter for the equator and another at right angles for the central meridian. Divide each quadrant into ten-degree distances—that is, nine equal parts—and each radius into the same number of parts. Make each parallel the arc of a circle that shall pass through the extremities of the proper arcs, and the corresponding point on the central meridian. Draw each meridian through the poles and its established point on the equator.

Judged critically, the projection constructed in this manner is not without defects. It gives neither correct area, outline, nor direction. These defects are by no means fatal, however, and at least two of them are possessed by every other projection. The chief advantage is that it distorts less than any of the true perspectives and projections. In spite of all that can be said against it it is one of the best constructions ever devised for the map of a hemisphere, and in several elaborate atlases it is employed as the most desirable projection therefor.

There remains one other arbitrary construction of similar character, which is usually employed as a projection for maps of the polar regions, or even for maps of the whole sphere. The construction will be self-explanatory.

In the legitimate work of surveying and engineering there are but few occasions in which a map of a hemisphere is required, and when needed it is usually in the form of a small vignette supplementary to a larger map. Generally it will suffice if the meridians and parallels are twenty or even thirty degrees apart. It is customary to make the meridian of Ferro, longitude 340°, the boundary between the Eastern and Western hemispheres.

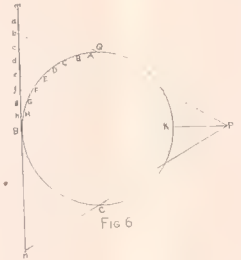


Fig 6

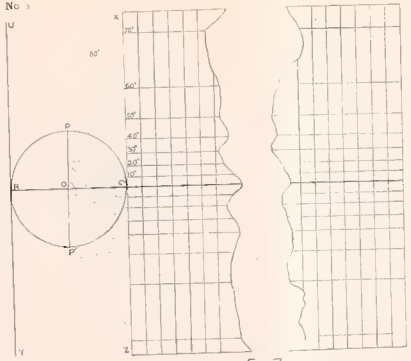


Fig. 7.

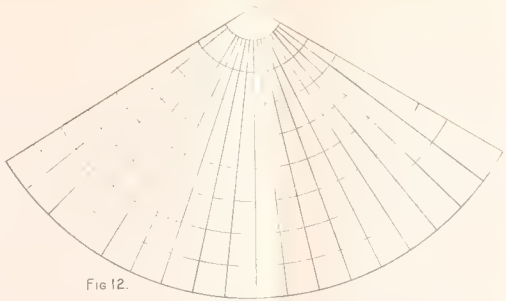


Fig 12.

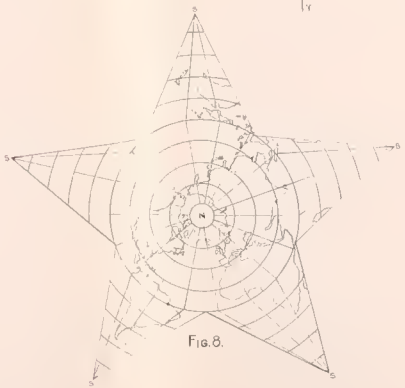


Fig. 8.

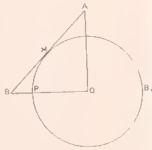


Fig 9



Fig 10

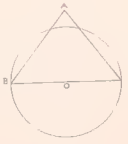


Fig. 11.

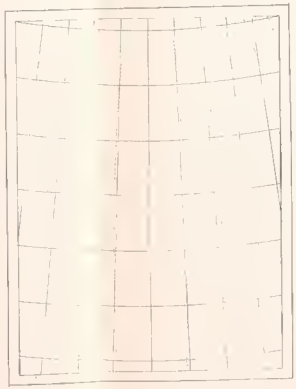


Fig 13

Mercator's Projection.—It is often necessary to chart the entire surface of the sphere on a single continuous sheet. For this purpose there are two projections that answer the requirements—Babinet's homalographic and Mercator's. In practice, however, the latter is almost universally used. In this projection the surface of the sphere is developed on a tangent cylinder. If we conceive the outlines of the continents to be drawn on this, and afterwards the surface to be unrolled and laid flat, the result is a chart on the Mercator projection. The development of the surface of the sphere upon that of the cylinder is very easy, and so far as mechanical difficulties are concerned it is the easiest of all projections to construct.

Let PQP' (Fig. 7) be a sphere, AB its diameter and $UXYZ$ a portion of the tangent cylinder in the axis of which is contained the axis of the sphere. Divide the quadrant PQ into any desired number of parts. The point at which each secant drawn through the extremity of the arc meets the tangent, will be the locus for the parallel of that degree. It is evident that the loci of the points, where the secants intersect the tangent, is nothing more than a table of natural tangents, multiplied by any convenient coefficient. Make the equator of the projection somewhat longer than 3.1416 times the diameter of the cylinder—say, $2\pi R + \frac{2\pi R}{24}$, and divide it into twenty-five equal parts. Each division, then, will be the position of an hour meridian. The extra $\frac{1}{24}$ is added for convenience merely, so that a small portion of the area on the left side of the map may be repeated on the right side. The reason for taking meridians at hour distances—that is, 15 degrees apart—is obvious in the case of sailing charts; in maps designed for other purposes, any other convenient divisions may be made.

In this projection the exaggeration of areas and outlines is very great, increasing from the equator towards the poles. A degree of longitude, which should be about 40 statute miles in latitude 55°, and nothing at the poles, is made 69 statute miles in each case; the distance between parallels increases by a constantly increasing coefficient, and inasmuch as the secant of 90° will never meet the tangent, the parallel of 90° will be projected into infinite space.

Now, although this is the Mercator projection of theory, it is not that of practice. In the construction of physical maps, such as wind-charts, current-charts, etc, the equatorial regions, in which details must be minutely entered, are inconveniently narrow, while in high latitudes they are unnecessarily wide. For nautical purposes, there needs be an important modification. On a chart projected in the foregoing manner truth of direction is preserved along all north-and-south and east-and-west lines. Moreover, any straight line drawn upon the chart will be a great circle on the sphere. But in navigation something more than this is required; for inasmuch as a true loxodromic curve cuts all meridians of the sphere at equal angles, so also must the corresponding line upon the chart make equal angles with the representatives of the curvilinear elements. Still, further, to give the greatest practical accuracy the sphere must be replaced by the spheroid; so between the two requirements, the formula:

$$s = \tan \phi$$

must be replaced by one much more complex. In order to meet these requirements Assistant Thomas Craig, U. S. Coast Survey, has deduced the following, from which the table at the end of this paper has been prepared:

$$s = 7915.704764' \log. \tan. \left(45° + \frac{\phi}{2}\right) - 3437.7' \left(\epsilon^2 \sin \phi + \frac{\epsilon^4 \sin^3 \phi}{3} + \ldots\right)$$

in which s = distance in minutes of equatorial arc from the equator to the parallel to be established; ϕ, the latitude of the parallel, and ϵ the eccentricity of the earth along the polar diameter. The last term of the formula is a series, and inasmuch as ϵ has a fractional value, the series is evidently convergent. All terms containing a power higher than the fourth may consequently be omitted.

The only points concerning the formula open to criticism are the assignment of a value to ϵ, and the assumption that the earth is a spheroid. In the table prepared by Mr. Craig, the ellipticity of the earth is assumed taken at $\frac{1}{303}$; other valuations are as high as $\frac{1}{299.15}$. The actual value of ϵ is still more or less problematical, but even if the true value lies outside the value noted, the difference would not be appreciable. Even the fact that the earth is not a true spheroid, does not practically affect the values

of s, so comparatively small is difference between a spheroid and the geoid.

The tables are, therefore, sufficiently accurate for the closest work in navigation; for the construction of ordinary physical charts even the roughest values will answer. In fact, for such charts expansion in low, and contraction in high, latitudes, is frequently desirable.

Babinet's Projection.—This projection, invented by Mollweide, was first generally applied by Babinet; it is also known as the *homalographic* projection. Its use is commonly restricted to physical charts, and it is useful for this purpose because the whole surface of the earth may be shown on one continuous plane. The bounding line of the map is an ellipse. The following is a convenient method of constructing it: Draw an ellipse whose major axis is just double the minor axis; the former will be the equator; the latter, the central meridian. Divide the equator into any convenient number of parts, and the points of division will be the loci of the meridians, the latter being drawn from the extremities of its central meridian, each cutting the equator in its established point. The parallels are drawn parallel to the equator, the distance of each from the center being $R \mid 2 \sin. \lambda$ in which R is one-half the minor axis, and λ the angle which a line drawn from the extremity of the parallel to the center makes with the equator. The following table gives the values of sin. λ for each 5°:

Lat.	Sin. λ	Lat.	Sin. λ	Lat.	Sin. λ	Lat.	Sin. λ
5	.0685	30	.4040	55	.7080	80	.9454
10	.1368	35	.4682	60	.7624	85	.9784
15	.2047	40	.5310	65	.8138	90	1.000
20	.2720	45	.5920	70	.8619		
25	.3385	50	.6512	75	.9060		

The location of the parallels, according to this formula, makes the zones of the map equal in area to the zones of a sphere having the

same radius. Unless there is reason for preserving this equivalence of areas, however, the following equidistant projection will be found more satisfactory. Draw an ellipse whose axes are 2 : 1; the axes will be the equator and the central meridian. To locate the parallels, divide each quadrant of the ellipse into any convenient number of parts—say nine—and each half of the central meridian into the same number; each parallel is the arc of a circle drawn through the extremities of the proper quadrant divisions and the corresponding division of the central meridian. Divide the equator into hour divisions; make each meridian an ellipse passing through the poles and its proper locus on the equator. It is hardly necessary to say that this projection is not homalographic, but it is certainly an available one.

For all the requirements demanded by the surveyor, engineer or geographer, the reduced chart of the Mercator projection is decidedly superior to the homalographic or its equidistant substitute. In fact the only advantage of the latter is that of artistic appearance. Still another device for exhibiting the entire surface of the sphere has been already mentioned, and this, though of limited application, is worthy of the brief description given in the following paragraph.

Polar Projection.—The accompanying cut (Fig. 8) needs but little explanation. Strictly speaking, it is a perspective, but is described here inasmuch as the uses to which it is applied are similar to those for which Mercator's and Babinet's are designed. The point of sight is always in line with the axis, and the projection may be either orthographic or stereographic. Practically it is best to make it equidistant, drawing the parallels at equal intervals. The number of lines and their boundaries is a matter of discretion and fancy of the draughtsman.

It will have undoubtedly occurred to the reader that a fixed scale of miles for any of the foregoing projections is out of the question. In no instance are the parallels equidistant throughout their entire extent, and in several instances the distortion of distance extends to the meridians as well. By means of Table II. approximate distances may be easily found.

We now come to a series of projections that embraces the great

bulk of maps used for atlases, geographical publications, railway folders and the various maps issued by the Land Office, Coast Survey, and the Geological Survey. In quality they vary from the rough, gaudily-colored daubs that, by a stretch of courtesy, are called educational wall-maps, to the beautiful engravings published by the Coast and Geological Surveys. It is doubtful if anything short of a special act of Providence could give birth to a more beastly specimen of cartography than the average American wall-map designed for educational purposes. It is equally true that no country under the sun produces maps of higher artistic merit or scientific value than the United States Coast and Geological Surveys. In the various series of projections which these maps display, one may choose between any degree of accuracy and consistency. In general, however, the draughtsman must decide between equivalence of area and proportionate outline. That is, if the outline of the area is geometrically similar to the outline projected on the chart, to the closest degree of approximation, true equivalence of areas must be sacrificed. On the other hand, if equivalence of areas is preserved, then there must also be a distortion of outline. Hence, so long as the cartographer is called upon to project a spherical earth on a plane surface, he must compromise between impossibilities.

All the projections employed are practically variations of a single development, namely, the surface of a sphere on that of a cone. The cone, moreover, may be tangent to the sphere at a parallel to be decided upon; it may intersect the sphere by cutting the latter at any two parallels; or it may be a polycone—that is tangent to the sphere at every projected parallel. A section of the last-named figure through the center of the sphere is nothing more than a polygon circumscribed about a circle.

The Conic Projection.—The conic projection is the simplest of all developments. Instead of being drawn on the surface of a sphere, the map is projected on the surface of a cone. Let us first consider the case in which the projection is developed upon a tangent cone.

In Fig. 9, AM is the distance from the apex of the cone to the middle parallel and point of contact, and ϕ the latitude of contact. Then AM will be the radius for the parallel, and A

the center from which all parallels are drawn. Now the radius for the parallel, drawn through M, the central parallel of the map, is manifestly R cot. ϕ; R being the radius of the sphere. The arc PM is $90°—\phi$ degrees of a circumference and its length is $\frac{\pi R (90° — \phi)}{180°}$. We may either lay off the length of the arc PM on the central meridian, or we may subdivide the latter into as many parts as there are degrees in the arc. If we do the former there will be a measurable exaggeration in the length of a degree of latitude when compared with a degree of longitude at the tangent parallels; if the latter, we shall have an exaggeration in longitude increasing from the parallel of contact. In this case the pole, which should be a point, becomes a circular section of the tangent cone. In many instances, especially if the extent of latitude is not great, this plan is desirable. We may eliminate errors of longitude still further by taking the exact length of the arc PM, striking a new central parallel and spacing off equal fractional parts along the central meridian through which the parallels shall be drawn.

For maps, including not more than 30 degrees of latitude, the projection of the tangent cone is fairly serviceable. It is evident, however, that the errors of longitude cannot be wholly eliminated even by the device last described. This device, moreover, makes the cone an intersecting cone, and a rather undesirable one at that, inasmuch as it intersects the sphere along one parallel only.

The platting of a conic projection is very simple. Draw the central meridian and determine what shall be the parallel of contact. Find the length of an arc of 90° less the latitude of the parallel of contact, and lay off the length of this arc on the central meridian. The upper extremity will be the center from which the parallels are to be drawn; the lower extremity, the position of the parallel that is common to both the sphere and the cone. Suppose the parallel of contact to be the 30th, then the length of the radius for drawing the parallels will be equal to an arc of 60 degrees on a great circle of the sphere. Lay off the length of this arc on the central meridian, and if the parallels are to be ten degrees apart, divide it into, say, six equal parts.

Lay off three or four divisions below the parallel of contact, and with the upper extremity as a center draw arcs through the points of division. Find the required eastern and western limits of the map, and on the parallel of contact lay off the required number of degrees. Divide the latter into a convenient number of parts and the projection is completed (see Fig. 12).

Although this development is frequently described in connection with the tangent cone, it is evident that it is a development of an intersecting cone. It answers fairly well for maps of small areas, and in several small atlases the map of Europe has been projected in this manner. If we conceive the cone to intersect the surface of the sphere in two places, however, we shall get better results in a much easier and satisfactory manner.

To develop a projection by means of the intersecting cone, let us suppose that the parallels of contact be taken one-third the distance from the upper and lower margins of the map, and, as an example, let us project a map of England. Draw the central meridian, which in this case will be longitude 2° W. An inspection of any map will show that the 52d and 54th parallels will be the most available parallels of contact. The length of one degree on a meridian of the earth (Table II.) is 69.12* miles. On the central meridian, about one-third the distance from the upper extremity, establish a point for the intersection of the 54th parallel, and at a distance of 138.24 units (2 degrees) fix the point of intersection for the 52d parallel. The map units may be of any convenient length, according to the size of the map, scaled off on a paper rule. Referring again to the table we find the length of a degree of longitude, at latitude 54, to be 40.74 miles. With a radius of 40.74 units, at the intersection of the 54th parallel with the central meridian, draw an arc on each side of the meridian. Again, at the intersection of the 52d parallel and the meridian, by means of the table, draw an arc on each side of the meridian with a radius 42.67 units in length. Now draw lines tangent to these arcs; the tangents produced will meet, and the point of their intersection will be the center from which the parallels are

* A degree of latitude at the equator is about 68.5 statute miles; at the poles 69.12.

to be drawn. Draw the parallels, and by means of the table space off the values of each degree, or multiple thereof, on the parallels of contact. Draw the meridians through these points and the projection is completed. For the map of an area covering not more than 100,000 square miles, this projection will be found a most excellent one. In fact it can be improved only by marking off the proper meridian distance on each parallel, and drawing a meridian through each series of divisions by means of a flexible rule. By this modification the development becomes Bonne's projection.

Bonne's Projection.—The foregoing paragraph outlines the manner in which this projection is developed from that of the intersecting cone. Generally, Table III. furnishes a more expeditious method of finding the radius for the parallels. Determine which is to be the central parallel of the map, and draw the central meridian. With the radius for the central parallel draw an arc of the required length. On the central meridian lay off any convenient number of divisions through which the parallels are to be drawn, and from the common center draw the remaining parallels. On each parallel lay off the lengths designated in the table, and, by means of a flexible rule, pass a line through each series. Fig. 13 is a comparison of Bonne's and conic projections.

In some instances it may be advisable to find the exact length of an arc extending from the pole to the parallel of contact, and taking this as a radius for that parallel. The length of this arc is, of course, $\frac{\pi R (90° - \phi)}{180°}$. The actual length of a degree, or its multiples, may be spaced off on the central meridian. The lengths of the degrees, fractions or multiples may then be spaced off on the respective parallels and the meridians drawn with a flexible ruler.

The great advantage of Bonne's projection is that true proportion of areas is preserved; the only disadvantage is an observable marginal distortion where large areas are to be charted. The meridians towards the margin cut the parallels at an oblique angle—acute near the top and obtuse at the bottom of the map. In the first method given, there will be notably less distortion of outline, but the equality of areas will not be so well preserved.

For wall-maps, or for maps on which the scale of miles is not required to be used, the first plan gives a better-looking map. For maps of precision, however, the latter method should be employed. In maps of small areas the distortion can be discovered by close measurements only.

The maps of nearly all the better class of atlases, such as Johnston's, Stieler's, Kiepert's, Perthes's and Andrées's, are commonly drawn on this projection. It is officially used for the military and civil maps of France, tables for that territory having been especially constructed by Plesses. For county maps, state maps and even the map of the United States, the engineer and surveyor will find it a most superior projection, both in facility of construction and results obtained.

Flamsteed's Projection.—In the consideration of the conic projection, it is evident that the nearer the circle of tangency approaches the equator the longer will be the radius for drawing it, and when the latter coincides with the equator, the radius becomes infinity. Now, in Flamsteed's projection the latitude of contact is assumed to be at the equator, and inasmuch as the radius is of infinite length, the arcs drawn by it are right lines. In constructing the projection, draw the equator as the central parallel and bisect it by the central meridian. On the central meridian lay off the degrees, fractions or multiples in "rectified lengths," that is, in terms of 68.5 statute miles. On each parallel lay off successively the length of the degree of longitude or any convenient multiple, and with a flexible rule draw a line through each series of points.

This projection is most suitable for such areas only as are traversed by the equator and whose limits do not extend into high temperate or polar regions; it is, therefore, well adapted for Africa, South America or Oceania. From the nature of its construction it is evidently a modification of Bonne's projection.

The Polyconic Projection.—We now come to a method of development in which, instead of a single tangent cone, there is employed one for each parallel. In this, as in the conic projection, we must sacrifice either proportionate outline or equality of areas. We cannot have both. We can modify it to secure either, however, as in other conical developments. In the former case it is

commonly known as the *rectangular*, in the latter, the *oblique* polyconic projection. In either case the radius of the tangent parallel is equal to the cotangent of the latitude, that is $R = \cot. \phi$. It is quite convenient, however, to use a table in which the cosine of 1° is taken as a unit, and Table III. has been constructed, on this basis. It may be readily deduced that the radius of this sphere is 57.296, a factor commonly represented by N, hence our formula becomes $R = N \cot. \phi$, for the sphere.

The construction of the polyconic projection is simple. Draw the central meridian and on it lay off the lengths of each degree of latitude or multiple; the parallels are to be passed through the extremities of these divisions. Each parallel has a different center, and its length is given opposite the proper degree in the table. If a rectangular projection is required, each projected meridian must be drawn so as to cut every parallel at right angles, and for wall-maps, or where true outlines are required, this method is preferable. Where equality of areas is desired, the value of the degree or multiple thereof is spaced off, each along its proper parallel, and by means of a flexible rule a meridian is passed through each series.

Table III. is corrected approximately for the spheroid. For work so precise as that demanded by the Coast Survey more complex tables are required, and, as they are too voluminous to be included in this paper, the cartographer is referred to the special publication of that office.

The table given, although handy, is not essential, and may be replaced by a table of lengths of a degree of longitude (Table II.) Draw the central meridian and along it space off the required divisions for the parallels. At each point of division, on opposite sides of the central meridian, strike an arc whose radius is equal to the length of a degree of longitude or multiple thereof for that latitude. With a flexible rule draw a curved tangent to each set of arcs. Using each of these developed meridians, and with the points of contact as centers, strike another set of arcs, each radius having a value according to its latitude. With the flexible rule draw tangent curves and thus establish two other meridians, one east and the other west. Proceed in this manner until all the meridians are laid off. The parallels may be then drawn, each

passing through the proper series of points of contact. The center for each parallel will, of course, be on the central meridian produced; the radius may be found by trial or by the ordinary geometric theorem.

Compared with Bonne's, the polyconic projection has never obtained the popularity among cartographers enjoyed by the former. Where a large area, such as the grand division of Eurasia, is to be charted, marginal exaggeration or distortion becomes so apparent as to be a serious defect. If we represent the whole surface of the spheroid continuously, the area is

$$\left[(4+\pi^2)\tan^{-1}\frac{\pi}{2}+2\pi\right]R^2.$$

This value, compared with $4\pi R^2$, the surface of the sphere, has about the ratio 8:5. In charting small areas, however, or those of no considerable extent of longitude, it is a very superior projection. The fact that it is used by the Coast Surveys, both of the United States and Great Britain, is evidence of its excellence for such work.

There are many other projections more or less meritorious, but the foregoing comprise about everything necessary for the practical work of the surveyor and engineer, and the tables appended are sufficiently comprehensive for all purposes, except actual geodetic work. The individuality of the cartographer is always a factor to be considered, and, generally speaking, one that needs but little modification, much less elimination. For this reason, the descriptive work in this paper is intended in the light of suggestions only. In the author's experience, Bonne's projection for large, and that of the intersecting cone for small, areas are the most practical and the best for all the cartography the average engineer and surveyor will ever be called upon to superintend. So far as the science of cartography is concerned, the demands upon an engineer are more limited than those which the geographer is called upon to meet; but, on the other hand, they are more exacting. On the whole, the two projections noted meet the exactions better than any others.

In the mechanical work of constructing the projections but little advice can be offered. Every draughtsman has his own way of constructing scales, spacing, subdividing, etc., and any

suggestions here would be superfluous. Perhaps the drawing of the curved meridians will be more difficult than any other part of the work. Some time ago the author purchased a flexible rule known in the trade as the "adjustable-curve rule." It consists of a thin steel strap in front of a bar of lead held in a long spiral coil. The latter is a retaining-coil, and its coefficient of resistance is greater than that of the elasticity of the strap. Unfortunately the eyes which hold the retaining-coil are riveted to the strap, and the latter in consequence is not uniformly elastic. It is a great pity that this defect exists, as it lessens the value of the rule in no small degree. The old method of using flexible splines and retaining weights is a slower, but, on the whole, a better way.

It is hardly necessary, either, to dwell on the use of the conventional signs used in cartography. As a rule, the engineer's work is better than that of the engraver. It may not be quite so neatly done, but it certainly possesses more character. The wretched hachuring done by the average engraver is the result of ignorance of physiography and topography, but the draughtsman is not infrequently to blame in sacrificing character in order to produce a neat and artistic original for the engraver. Now, character is everything in a map, and if both cartographer and engraver have done their work faithfully, the map will show the physiography of a region as clearly and distinctly as the descriptive printed page.

TABLE I.

MERCATOR'S PROJECTION—DISTANCES OF DEVELOPED PARALLELS FROM THE EQUATOR, IN MINUTES OF ARC.

Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0	0.0	11 30	690.1	18	1091.2	24 30	1507.5	31	1946.3	37 30	2416.5	44	2930.0
1	56.9	12	720.6	18 30	1122.6	25	1540.4	31 30	1981.2	38	2454.2	44 30	2971.7
2	119.2	12 30	751.1	19	1154.1	25 30	1573.4	32	2016.3	38 30	2492.3	45	3013.8
3	178.9	13	781.7	19 30	1185.7	26	1606.5	32 30	2051.6	39	2530.6	45 30	3056.3
4	238.6	13 30	812.3	20	1217.4	26 30	1639.8	33	2087.1	39 30	2569.2	46	3099.2
5	298.4	14	843.0	20 30	1249.1	27	1673.2	33 30	2122.8	40	2608.1	46 30	3142.4
6	358.3	14 30	873.7	21	1281.0	27 30	1706.8	34	2158.8	40 30	2647.2	47	3186.1
7	418.3	15	904.6	21 30	1313.0	28	1740.5	34 30	2194.9	41	2686.7	47 30	3230.1
8	478.4	15 30	935.5	22	1345.2	28 30	1774.4	35	2231.2	41 30	2726.4	48	3274.6
9	538.7	16	966.5	22 30	1377.4	29	1808.4	35 30	2267.8	42	2766.5	48 30	3319.5
10	599.1	16 30	997.5	23	1409.7	29 30	1842.6	36	2304.6	42 30	2806.9	49	3364.9
10 30	629.4	17	1028.6	23 30	1442.2	30	1877.0	36 30	2341.7	43	2847.6	49 30	3410.7
11	659.7	17 30	1059.9	24	1474.8	30 30	1911.6	37	2378.9	43 30	2888.6	50	3457.0

TABLE I—(Continued).

MERCATOR'S PROJECTION—DISTANCES OF DEVELOPED PARALLELS FROM THE EQUATOR, IN MINUTES OF ARC.

Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.	Lat.	Dist. from Eq. in Min.
° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
50 30	3503.8	56 30	4108.9	62 30	4819.2	68 30	5690.6	74 30	6834.3	80 30	8529.9	86 30	11969.2
51	3551.1	57	4163.5	63	4884.7	69	5773.3	75	6948.4	81	8716.6	87	12499.4
51 30	3598.9	57 30	4218.9	63 30	4951 2	69 30	5857.9	75 30	7062.2	81 30	8913.8	87 20	12904.5
52	3647.3	58	4275.0	64	5019.0	70	5944.5	76	7188.0	82	9122.9	87 40	13363.7
52 30	3696.1	58 30	4331.9	64 30	5087.9	70 30	6033.2	76 30	7314.2	82 30	9345.4	88	13893.7
53	3745.6	59	4389.6	65	5158.2	71	6124.2	77	7445.0	83	9583.2	88 20	14520.6
53 30	3795.6	59 30	4448.2	65 30	5229.8	71 30	6215.5	77 30	7580.0	83 30	9838.6	88 40	15287.7
54	3846.2	60	4507.7	66	5302.7	72	6313.2	78	7722.3	84	10114.3	89	16267.8
54 30	3897.5	60 30	4568.0	66 30	5377.1	72 30	6411.5	78 30	7869.6	84 30	10413.9	89 20	17670 7
55	3949.3	61	4629.3	67	5453.1	73	6512.7	79	8023.4	85	10741.9	89 40	20053.6
55 30	4001.8	61 30	4691.6	67 30	5530.6	73 30	6616.7	79 30	8184.2	85 30	11104.5	90 00	∞
56	4055.0	62	4754.9	68	5609.7	74	6723.9	80	8352.8	86	11509.8		

TABLE II.

THE LENGTHS OF ONE DEGREE OF LONGITUDE IN EACH DEGREE OF LATITUDE.

Lat.	Stat. Mi.	Lat.	Stat. Mi.	Lat.	Stat. Mi.	Lat.	Stat. Mi.	Lat.	Stat. Mi.	Lat.	Stat. Mi.
°		°		°		°		°		°	
0	69.164	16	66.499	32	58.711	48	46.363	64	30.402	80	12.049
1	69.145	17	66.163	33	58.065	49	45.462	65	29.310	81	10.854
2	69.122	18	65.798	34	57.397	50	44.545	66	28.210	82	9.656
3	69.072	19	65.419	35	56.714	51	43.614	67	27.101	83	8.456
4	68.998	20	65.014	36	56.018	52	42.670	68	25.985	84	7.253
5	68.901	21	64.589	37	55.308	53	41.713	69	24.860	85	6.048
6	68.785	22	64.156	38	54.570	54	40 743	70	23.725	86	4.840
7	68.652	23	63.695	39	53.819	55	39.760	71	22.584	87	3.631
8	68.496	24	63.216	40	53.053	56	38.765	72	21.437	88	2.421
9	68.315	25	62.718	41	52.269	57	37.758	73	20.284	89	1.211
10	68.117	26	62.202	42	51.476	58	36.740	74	19.124	90	0.000
11	67.900	27	61.666	43	50.660	59	35.710	75	17.957		
12	67.661	28	61.113	44	49.830	60	34.669	76	16.784		
13	67.403	29	60.537	45	48.892	61	33.617	77	15.608		
14	67.121	30	59.947	46	48.124	62	32.555	78	14.427		
15	66.821	31	59.333	47	47.253	63	31.483	79	13.240		

TABLE III.

POLYCONIC PROJECTION.—LENGTHS OF DEGREE OF LONGITUDE FOR EACH DEGREE OF LATITUDE, AND RADII OF PARALLELS.—COS. 1° = UNITY.

Lat.	Length of Deg. of Long.	Rad. of Parallel.	Lat.	Length of Deg. of Long.	Rad. of Parallel.	Lat.	Length of Deg. of Long.	Rad. of Parallel.	Lat.	Length of Deg. of Long.	Rad. of Parallel.
°			°			°			°		
0	1.000	∞	23	.920	134.980	46	.694	55.330	69	.358	21.194
1	.999	3282.473	24	.913	128.688	47	.682	53.429	70	.342	20.854
2	.999	1640.736	25	.906	122.871	48	.669	51.589	71	.325	19.729
3	.998	1093.268	26	.899	117.474	49	.656	49.806	72	.309	18.617
4	.997	819.368	27	.891	112.449	50	.643	48.077	73	.292	17.517
5	.996	654.894	28	.883	107.758	51	.629	46.397	74	.275	16.429
6	.994	545.133	29	.874	103.364	52	.615	44.764	75	.259	15.352
7	.992	466.637	30	.866	99.239	53	.602	43.175	76	.242	14.285
8	.990	407.681	31	.857	95.356	54	.588	41.628	77	.225	13.228
9	.987	361.751	32	.848	91.962	55	.573	40.119	78	.208	12.179
10	.984	324.940	33	.838	88.228	56	.559	38.646	79	.191	11.137
11	.981	294.761	34	.829	84.944	57	.544	37.208	80	.174	10.103
12	.978	269.556	35	.819	81.827	58	.529	35.802	81	.156	9.075
13	.974	248.175	36	.809	78.861	59	.515	34.427	82	.139	8.052
14	.970	229.801	37	.799	76.034	60	.500	33.080	83	.122	7.035
15	.965	213.831	38	.788	73.335	61	.485	31.760	84	.104	6.022
16	.961	199.814	39	.777	70.254	62	.469	30.465	85	.087	5.013
17	.956	187.406	40	.766	68.282	63	.454	29.194	86	.070	4.007
18	.951	176.338	41	.755	65.911	64	.438	27.945	87	.052	3.001
19	.945	166 399	42	.743	63.633	65	.423	26.717	88	.035	2.001
20	.939	157.419	43	.731	61.442	66	.407	25.510	89	.017	1.000
21	.933	149.261	44	.719	59.332	67	.391	24.321	90	.000	0.000
22	.927	141.812	45	.707	57.296	68	.374	23.149			

XV.

RECENT EXPERIMENTS ON THE FLOW OF WATER OVER WEIRS.

By M. Bazin, Inspector-General of Bridges and Highways.

Reprint from Annales des Ponts et Chaussées, October, 1888.

Translated by Arthur Marichal and John C. Trautwine, Jr., Active Members of the Club.

Part II (*a*).

In a former communication (Annales des Ponts et Chaussées, 1888, Vol. 2, p. 393),* we determined the coefficients of discharge for cases where the sheet of water discharges freely into the air over vertical weirs in thin partition; and, by using weirs of different heights, we showed how these coefficients are affected by the velocity of approach. We now proceed to study the form of the sheet of water passing over the weir,† and we shall extend our investigations to cases where the up-stream side of the weir (hitherto assumed to be vertical) is inclined up or down stream (Figs. 9 and 10, Pl. 1). Such inclination modifies not only the form of the sheet, but also the coefficients, the latter being intimately related to the contraction which takes place at the crest of the weir.

The upper surface of the nappe has already been studied by certain experimenters, but the under surface, while less easy to observe, is, perhaps, of greater interest from a theoretical standpoint; for its form shows accurately the contraction at the crest. In forming this contraction, the under side of the nappe leaves the crest at a certain angle, rising at first, then becoming horizontal, and finally falling. This upward curve of the under side of the nappe, scarcely noticed until now, constitutes, nevertheless, one of the fundamental data of the phenomenon, and M. Boussinesq has made it the basis of a new theory of the flow over weirs.‡

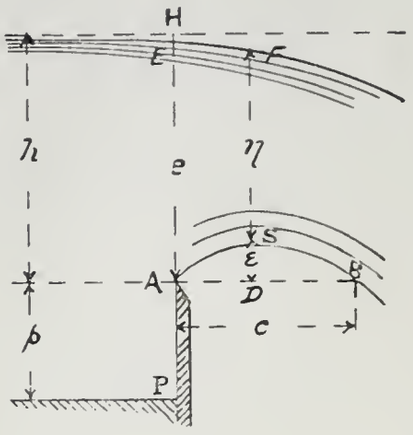
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* Translated in Proceedings Engineers' Club of Philadelphia, Vol. VII, No. 5, January, 1890.

† For want of a convenient English equivalent, we shall designate this sheet by its very appropriate French name, the *nappe*, a name applied primarily to a table-cloth, the form of which, as it passes from a horizontal to a vertical plane in passing over the edge of the table, is well imitated by the sheet of water passing over the weir.—Translators.

‡ Comptes rendus de l'Académie des sciences, July 4, 1887.

In our discussion we shall make use of the following symbols:



ϵ = the small elevation $S\,D$ of the nappe above the crest A of the weir.

c = the chord $A\,B$.

e = the vertical depth $A\,E$ of the nappe immediately over the crest.

η = the vertical thickness $S\,F$ of the nappe over the summit S of the curve $A\,S\,B$.

h = the head $A\,H$.

p = the height $A\,P$ of the weir.

q = the discharge in cubic meters per second for each meter of length of the weir, $q = mh\sqrt{2gh}$.

M. Boussinesq's analysis has led him to adopt the formula:

$$q = 0.5216\sqrt{2g}\,(h-\epsilon)^{\frac{3}{2}} = 0.5216\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}} h\sqrt{2gh}.$$

$$q = 0.5216\sqrt{2g}\,(h-\epsilon)^{\frac{3}{2}}$$

$$= 0.5216\sqrt{2g}\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}} h^{\frac{3}{2}}$$

$$= 0.5216\sqrt{2gh}\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}} h$$

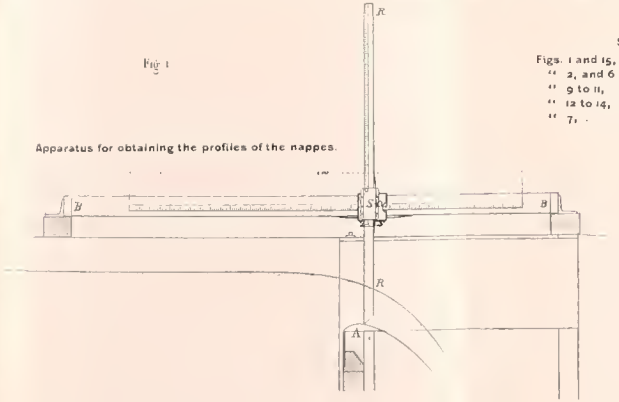
which is equivalent to substituting for the total head h or $A\,H$ in the usual formula—

$$q = mh\sqrt{2gh}.$$

$$= m\sqrt{2g}\,h^{\frac{3}{2}}$$

BAZIN-WEIRS.

Fig 1



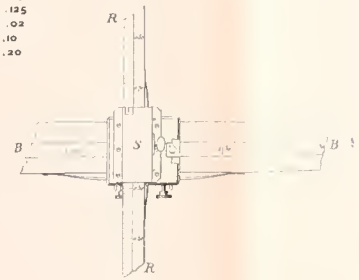
Apparatus for obtaining the profiles of the nappes.

SCALES.

Figs. 1 and 15,	$\frac{1}{20}$ or .05
" 2, and 6 to 8,	$\frac{1}{8}$ or .125
" 9 to 11,	$\frac{1}{50}$ or .02
" 12 to 14,	$\frac{1}{10}$ or .10
" 7,	$\frac{1}{5}$ or .20

Details of Sleeve.

Fig 2



Points for obtaining the profile of the lower curve of the nappe.

Fig 3. Section.

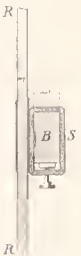


Fig 8

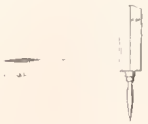
Point for obtaining the profile of the upper curve of the nappe.

Fig 4 Fig 5 Fig 6



Fig 7

Transverse section of Knife.



Inclined Weirs, 1m. 13 high.

Fig 9

Weir inclined 1 to 1 down stream

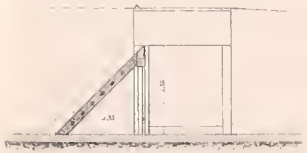


Fig 10

Weir inclined 3 to 2 up stream.

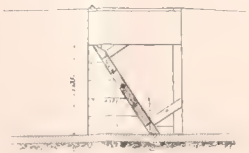


Fig 11 Wier inclined 1 to 4 down stream.



Crests terminating horizontally.

Fig 12

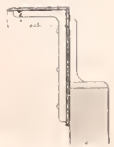


Fig 13

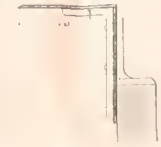


Fig 14



Fig 15 Elevation of crest terminating horizontally, looking down stream.



the value $h - \epsilon$, as though the crest were elevated to the point S, and making the coefficient 0.5216; or, in other words, it gives for the coefficient m in the formula $q = mh\sqrt{2gh}$ the value $m = 0.5216\left(1 - \frac{\epsilon}{h}\right)^{\frac{3}{2}}$, a value which, for a given head h, diminishes as ϵ increases. The ratio $\frac{\epsilon}{h}$ may thus be regarded as a sort of coefficient of contraction,* the introduction of which into the theory of the weir constitutes a notable advance. M. Boussinesq having kindly advised us of this result at the beginning of our experiments, in June, 1886, we have attached special importance to the exact determination of the elevation ϵ, and we have measured it with precision in the inclined as well as in the vertical weirs.

Methods Employed in Studying the Surface of the Nappe.

The determination of the profile of the upper surface of the nappe presented no difficulty; a wooden bar, $B\,B$ (Figs. 1, 2 and 3, Pl. 1), had been firmly fixed above the channel and parallel to its axis, and provided with a horizontal scale, upon which was a sleeve S, carrying a slide-rule $R\,R$ (règle à coulisse). The operation of this apparatus was simple in the extreme. The sleeve S being brought over the point, the height of which was to be determined, the slide-rule $R\,R$ was lowered until its point (Fig. 8, Pl. 1) just touched the surface of the water. Then, by reading the horizontal scale on the bar $B\,B$, and the vertical one on the slide-rule $R\,R$, the abscissa and the ordinate of the point were obtained.

The determination of the under surface was much more difficult. A pit dug alongside of the channel enabled us to observe it very closely; but it was impossible to operate a measuring apparatus from below the nappe, and the following method was resorted to: the slide-rule ($R\,R$, Fig. 1, Pl. 1) was provided at its lower end with a very sharp steel knife-edge, terminating in a

* In a recent study M. Boussinesq has modified this analysis, admitting that ϵ is a constant fraction of the height $D\,F$. This does not appreciably modify the results. Only the value of the coefficient is slightly diminished.

point (Figs. 4 and 7, Pl. 1); and this was plunged into the nappe. Owing to its thinness, it produced no sensible perturbation, and it was lowered little by little until its point reached the lower surface of the nappe. The contact was very clearly visible and could be observed, either from above, through the transparent nappe, or from below by standing in the pit just mentioned. When observed from above, a small white trail was seen to form on the surface of the nappe at the moment of contact. Viewed from below, this trail was seen equally well, and the emergence of the point was then also detected by the appearance of a black spot.

This convenient method was the one usually followed. However, in order to be able to check these observations and thus judge of the degree of approximation attained, we deemed it advisable to determine a number of sheets by observing the contact between their under sides and a point ascending from below. To accomplish this, we made use of another knife-edge, armed below with an upturned point (Fig. 5, Pl. 1) resembling that of the instrument employed in measuring the heads on the weir. This knife-edge, fixed to the lower end of the slide-rule *R R*, was first lowered clear through the nappe, and then gradually raised until the upturned point just touched the under side of the nappe. The two processes gave absolutely concordant results.

Form of the Nappe in Vertical Weirs.

The form of the nappe has been plotted for the two weirs 1.13 m. (3.7 feet) and 0.35 m. (1.15 feet) in height, for each of the heads given below:

Weir 1.13 *m.* (3.7 *feet*) *high.*—The two surfaces (upper and lower) of the nappe were measured with the descending point for heads of 0.152, 0.200, 0.252, 0.268, 0.300, 0.318, 0.345, 0.400 and 0.449 meters (say 6 to 17.7 inches).

The under surface alone was measured with the ascending point, for heads of 0.156, 0.200, 0.251, 0.276, 0.300, 0.325, 0.352, 0.400 and 0.449 meters (6.14 to 17.7 inches).

Weir 0.35 *m.* (1.15 *feet*) *high.*—Both surfaces were measured, with the descending point, for heads of 0.122, 0.152, 0.202, 0.250, 0.301, 0.353, 0.405 and 0.450 meters (4.8 to 17.7 inches).

The profiles of these nappes have been referred to two rectangu-

lar axes passing through the crest A, of the weir, the horizontal abscissæ x, being counted positive down stream and negative up stream, the ordinates y positive upward from the level of the crest and negative downward.

The tables of co-ordinates furnished by direct observation would occupy a considerable space. We have placed them at the end of this paper, inasmuch as a knowledge of the mean values deduced from them, or rather from their ratios, suffices for the following discussion. In fact, if we trace the profile of the nappes, by means of the co-ordinates x and y, we recognize at once that their form is nearly identical for all the heads. The curves which we have to study being thus nearly similar, it will be convenient to reduce them to one common scale, and to consider, not their absolute dimensions, but the ratios of these dimensions to the head h. We shall, therefore, substitute in this discussion the *ratios* $\frac{x}{h}$ and $\frac{y}{h}$ in place of the *absolute values* of x and y. We shall thus see that for each given value of $\frac{x}{h}$, whatever be the head, there is a corresponding and sensibly constant value of $\frac{y}{h}$; and if, taking as co-ordinates these two ratios, we plot upon a single diagram to a large scale* the position of each point of the profiles, the points thus obtained, for all the experiments of a single series, will be found to lie in a narrow zone, through the middle of which may be traced a very satisfactory curve (Figs. 1, 2 and 3, Pl. 2). Erecting to this curve the ordinates corresponding to equidistant abscissæ, 0.05, 0.10, 0.15, etc., we obtain the following values for the curve of the under surface, which we shall consider first.

* The scale adopted for these diagrams, which have been executed with the greatest care by M. Hegléy, was 0.50 m. to one meter.

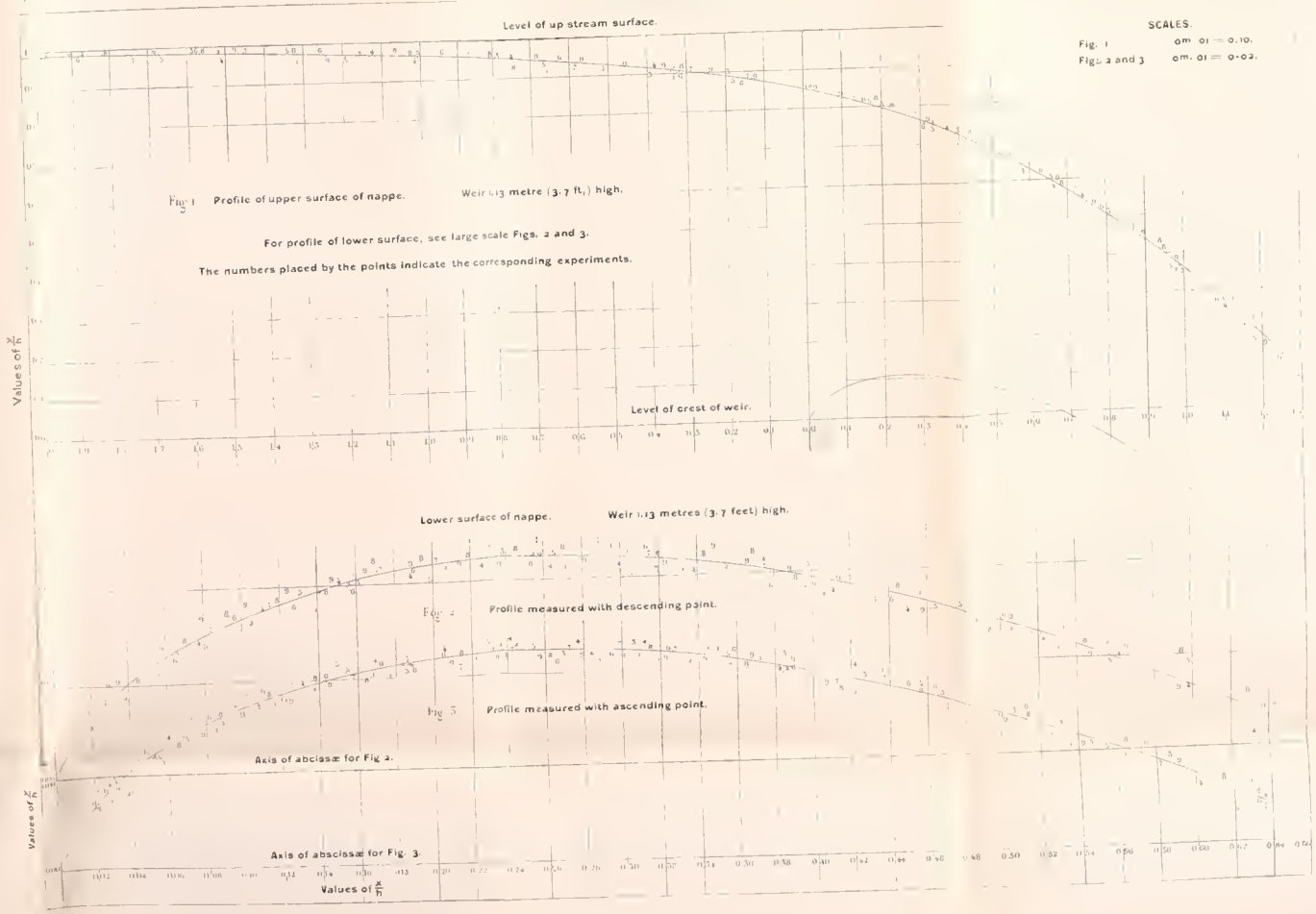
Form of Lower Surface of Nappe.

Table Showing Values of the Ordinates $\frac{y}{h}$ Corresponding to Abscissæ $\frac{x}{h}$ from 0 to 0.70.

		Values of $\frac{x}{h}$														
		0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70
WEIR 1.13 METER HIGH.																
Heads from 0.15m. to 0.45m.	Descending point (9 experiments)	0	0.058	0.084	0.101	0.109	0.112	0.111	0.106	0.097	0.085	0.070	0.053	0.034	0.012	—0.010
	Ascending point (9 experiments)	0	0.060	0.086	0.102	0.110	0.113	0.112	0.107	0.098	0.086	0.071	0.055	0.036	0.014	—0.008
	Means	0	0.059	0.085	0.101	0.109	0.112*	0.111	0.106	0.097	0.085	0.071	0.054	0.035	0.013	—0.009
WEIR 0.35 METER HIGH.																
Heads from	0.12m. to 0.30m. (5 experiments)	0	0.053	0.076	0.090	0.098	0.100	0.099	0.094	0.084	0.072	0.057	0.040	0.021	—0.001	—0.026
	0.35m. to 0.45m. (3 experiments)	0	0.052	0.075	0.088	0.095	0.097	0.095	0.090	0.080	0.068	0.053	0.036	0.018	—0.003	—0.027

* At the beginning of these researches we had assigned to the ratio $\frac{\epsilon}{h}$ too high a value (0.13 to 0.14), having observed from below the profile of the nappe on the sides of the channel. Later and much more precise observations showed that for a few centimeters from each side the nappe is locally superelevated, the upper surface also showing a projection beginning at the corner of the weir. In order to obtain the true value of ϵ it is necessary to avoid the vicinity of the sides of the channel. This value remains constant throughout the rest of the length of the weir.

BAZIN-WEIRS.


Level of up stream surface.
SCALES.
Fig. 1 om. 01 = 0.10.
Figs. 2 and 3 om. 01 = 0.02.
Fig. 1 Profile of upper surface of nappe.
Weir 1.13 metre (3.7 ft.) high.
For profile of lower surface, see large scale Figs. 2 and 3.
The numbers placed by the points indicate the corresponding experiments.
Values of h/c
Level of crest of weir.
Lower surface of nappe.
Weir 1.13 metres (3.7 feet) high.
Fig. 2 Profile measured with descending point.
Fig. 3 Profile measured with ascending point.
Axis of abcissæ for Fig. 2.
Values of h/c
Axis of abcissæ for Fig. 3.
Values of h/c

The two series of values obtained for the weir 1.13 m. (3.7 feet) high, one with the descending point and the other with the ascending point, scarcely differ at all (see Figs. 2 and 3, Pl. 2); the two methods of measurement checked each other perfectly, and the mean curve resulting from the comparison of the eighteen profiles is found to be determined with great precision. If we now pass to the weir 0.35 m. (1.15 feet) high, we at once recognize that the ordinates are all less than with the weir 1.13 m. (3.7 feet) high; that is to say, the curve is perceptibly flatter, the rise $\frac{\epsilon}{h}$ being reduced from 0.112 to 0.100 for heads from 0.12 m. to 0.30 m. (4.7 to 11.8 inches), and to 0.097 for greater heads. This modification is due to the influence of the velocity of approach; an influence, scarcely perceptible in the weir 1.13 m. (3.7 feet) high, but very important, on the contrary, in the lower weir, in which, for the last experiments of the series, the head h has exceeded the height p of the weir.

We have seen, in discussing the comparative experiments with weirs of different heights, that the coefficient of discharge m is approximately a linear function of the quantity $= \left(\frac{h}{h+p}\right)^2$. This quantity, which may be taken as a measure of the effect of the velocity of approach, varied in the weir 1.13 m. (3.7 feet) high, only between the narrow limits, 0.015 and 0.08; while with the weir 0.35 m. (1.15 feet) high, its extreme values are 0.065 and 0.315.

Let us now consider the upper surface of the nappe. Owing to its greater amplitude we shall plot it to a smaller scale (Fig. 1, Pl. 2) than the lower curve (Figs. 2 and 3).

Form of Upper Surface of Nappe.

Table Showing Values of the Ordinates $\frac{y}{h}$ Corresponding to Abscissæ $\frac{x}{h}$ from — 3.00 to + 0.70.

	Values of $\frac{x}{h}$									
	above the weir.		over the crest.	below the weir.						
	3.00	1.00	0	0.10	0.20	0.30	0.40	0.50	0.60	0.70
Weir 1.13*m. high.* Heads from 0.15m. to 0.45m. (9 experim'ts)	0.997	0.963	0.851	0.826	0.795	0.762	0.724	0.680	0.627	0.569
Weir 0.35*m. high.* Heads from 0.12m. to 0.45m. (8 experim'ts)	0.997	0.967	0.857	0.832	0.802	0.770	0.732	0.690	0.643	0.589

The ordinates for the upper curve are greater for the weir 0.35 m. (1.15 feet) high than for the higher one; that is to say, the sheet, as might be expected, is more elongated. This difference is readily explained, as is the flattening of the lower curve, by the influence of the velocity of approach. But we shall shortly have to consider more important modifications in the form of the nappe.

Experiments with Inclined Weirs.

In the weirs which we have considered until now, the up-stream side was a single vertical plane extending from the bottom of the channel to the sharp edge which constituted the crest of the wier. If we incline that surface to the vertical, we shall see that the coefficient m of discharge is notably modified. It increases when the weir is inclined down-stream, and decreases when the inclination is up-stream. At the same time the form of the sheet is also modified and the ratio $\frac{\epsilon}{h}$ varies inversely with m. In order to study the variations of these two quantities we have given to our weirs five different degrees of inclination (Figs. 9, 10 and 11, Pl. 1), as follows:

	Vertical.	Horizontal.		Vertical.	Horizontal.
Up and down stream	3	1	Down stream only	$\frac{1}{2}$	1
	$1\frac{1}{2}$	1		$\frac{1}{4}$	1
	1	1			

The corresponding ratios $\frac{\text{vertical}}{\text{horizontal}}$ $\frac{3}{1}$ $\frac{3}{2}$ $\frac{1}{1}$ $\frac{1}{2}$ $\frac{1}{4}$ are the tangents of the angles formed between the sloping back of the weir and the horizontal. In these experiments three weirs were used, respectively, 1.13 m., 0.50 m. and 0.35 m. high, and twenty series of experiments were made, viz: Series Nos. 11 to 30, as follows:

	Inclination							
	up-stream.			down-stream.				
	$\frac{1}{1}$	$\frac{3}{2}$	$\frac{3}{1}$	$\frac{3}{1}$	$\frac{3}{2}$	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{4}$
	Numbers of series.			Numbers of series.				
Weir 1.13m. high	11	12	13	14	15	16	17	18
Weir 0.50m. high	19	—	20	21	—	22	—	—
Weir 0.35m. high	23	24	25	26	27	28	29	30

The coefficients for the inclined weirs, 0.50 and 0.35 m. (1.97 and 1.15 feet) high (Series Nos. 19 to 30), were determined by comparing the heads observed upon these weirs and upon the vertical typical weir 1.13 m. (3.7 feet) high under a given discharge. As to the inclined weirs 1.13 m. high (Series Nos. 11 to 18), they were compared with the vertical weir 0.50 m. (1.97 feet) high, for which we had already obtained the value of the coefficient m_2 corresponding to different heads. The results of these twenty series of experiments are given in the following table:

Effect of Inclination of Weir upon the Coefficient **m**.

SERIES NOS. 11 TO 18.

Inclined weirs (I), 1.13 meter high, placed at the head of the channel.
Vertical weir (C), 0.50 meter high, placed 46 meters below weir I.

Experiment No.	Heads observed: on weir I. h	Heads observed: on weir C. H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir C. m_2	Coefficient: for weir I. m	Coefficient: for vertical weir 1.13m. high. M	$\frac{m}{M}$
	Meters.	Meters.						
Series No. 11.—inclination 45° up-stream. September, 1888. Temperature of water: 18° C. (64.4° Fahr.). Weir I: Height, 1.115 meter; Length, $l = 1.994$ meter. Weir C: " 0.502 " " " $L = 1.998$ " $\frac{L}{l} = 1.0020$.								
1	0.2404	0.2216	0.9218	0.8868	0.4410	0.3911	0.4258	0.919
2	0.2593	0.2386	0.9202	0.8845	0.4425	0.3914	0.4260	0.919
3	0.2793	0.2572	0.9209	0.8855	0.4443	0.3934	0.4263	0.923
4	0.2989	0.2746	0.9187	0.8823	0.4460	0.3935	0.4266	0.922
5	0.3173	0.2915	0.9187	0.8823	0.4476	0.3949	0.4269	0.925
6	0.3253	0.2985	0.9176	0.8807	0.4483	0.3948	0.4270	0.925
7	0.3364	0.3092	0.9191	0.8829	0.4493	0.3967	0.4272	0.929
8	0.3537	0.3239	0.9157	0.8780	0.4508	0.3958	0.4276	0.926
9	0.3707	0.3388	0.9139	0.8754	0.4523	0.3959	0.4279	0.925
10	0.3884	0.3550	0.9140	0.8756	0.4539	0.3974	0.4284	0.928
11	0.3914	0.3581	0.9149	0.8769	0.4542	0.3983	0.4284	0.930
12	0.4077	0.3720	0.9124	0.8733	0.4556	0.3979	0.4288	0.928
13	0.4281	0.3899	0.9108	0.8710	0.4575	0.3985	0.4293	0.928
14	0.4383	0.3989	0.9101	0.8700	0.4584	0.3988	0.4296	0.928
15	0.4489	0.4078	0.9084	0.8675	0.4593	0.3984	0.4299	0.927
Series No. 12.—inclination $\frac{3}{2}$ up-stream. August, 1888. Temperature of water: 17° C. (62.6° Fahr.) Weir I: Height, 1.133 meter; Length, $l = 1.998$ meter. Weir C: " 0.502 " " " $L = 1.999$ " $\frac{L}{l} = 1.0005$.								
1	0.1881	0.1777	0.9447	0.9187	0.4375	0.4019	0.4266	0.942
2	0.1995	0.1876	0.9404	0.9124	0.4382	0.3998	0.4262	0.938
3	0.2208	0.2064	0.9348	0.9043	0.4397	0.3976	0.4259	0.934
4	0.2415	0.2247	0.9304	0.8979	0.4413	0.3962	0.4258	0.930
5	0 2601	0.2422	0.9312	0.8990	0.4428	0.3981	0.4260	0.935
6	0.2794	0.2589	0.9266	0.8924	0.4445	0.3967	0.4263	0.931
7	0.2998	0.2786	0.9293	0.8963	0.4464	0.4001	0.4266	0.938
8	0.3180	0.2939	0.9242	0.8889	0.4479	0.3981	0.4269	0.933
9	0.3389	0.3133	0.9245	0.8894	0.4497	0.4000	0.4273	0.936
10	0.3594	0.3318	0.9232	0.8875	0.4516	0.4008	0.4277	0.937
11	0.3809	0.3501	0.9191	0.8816	0 4534	0.3997	0.4281	0 934
12	0.4012	0.3683	0.9180	0.8800	0.4552	0.4006	0.4286	0.935
13	0.4188	0.3845	0.9181	0.8801	0.4569	0.4021	0.4291	0.937
14	0.4344	0.3963	0.9123	0.8718	0.4581	0.3994	0.4295	0.930
15	0.4461	0.4069	0.9121	0.8715	0.4592	0.4002	0.4298	0.931

BAZIN-WEIRS.

Level of up stream surface.

Fig. 1

Profiles of upper and lower surfaces of nappes.

Weirs 1.13 m (3.7 feet) high.

Profile a — Inclined $\frac{1}{2}$ up stream

b — Inclined $\frac{1}{2}$ up stream

c — Inclined $\frac{1}{2}$ up stream

A — vertical

d — Inclined $\frac{1}{2}$ down stream.

e — Inclined $\frac{1}{2}$ down stream.

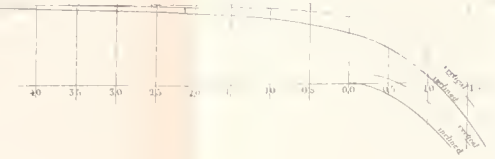
f — Inclined $\frac{1}{2}$ down stream.

g — Inclined $\frac{1}{2}$ down stream.

h — Inclined $\frac{1}{2}$ down stream.

Level of crest of weir.

Fig. 2. Comparison of profiles of nappes on vertical weir and on weir inclined $\frac{1}{2}$ down stream.



SCALES.

Fig. 1 om. 01 — 0.05.

Fig. 2 om. 01 — 0.50.

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* m_2	Coefficient: for weir *I.* m	Coefficient: for vertical weir, 1.13m. high. M	$\frac{m}{M}$
Series No. 13.—inclination $\frac{3}{1}$ up-stream. October, 1888. Temperature of water: 9° C. (48.2° Fahr.) Weir *I:* Height, 1.132 meter; Length, $l = 1.995$ meter $\left.\right\} \frac{L}{l} = 1.$ Weir *C:* " 0.502 " " " $L = 1.995$ " $\left.\right\}$								
	Meters.	Meters.						
1	0.1690	0.1614	0.9550	0.9333	0.4365	0.4074	0.4274	0.953
2	0.1809	0.1720	0.9508	0.9271	0.4371	0.4052	0.4269	0.949
3	0.1999	0.1906	0.9535	0.9311	0.4384	0.4082	0.4262	0.958
4	0.2193	0.2079	0.9480	0.9230	0.4398	0.4059	0.4259	0.953
5	0.2402	0.2272	0.9459	0.9200	0.4415	0 4062	0.4258	0.954
6	0.2593	0.2449	0.9445	0.9179	0.4431	0.4067	0.4260	0.955
7	0.2807	0.2658	0.9469	0.9214	0.4451	0.4101	0.4263	0.962
8	0.3003	0.2836	0.9444	0.9178	0.4469	0.4102	0.4266	0.962
9	0.3131	0.2958	0.9447	0.9182	0.4480	0.4114	0.4268	0.964
10	0.3319	0.3124	0 9412	0.9131	[illegible]96	0.4105	0.4271	0.961
11	0.3545	0.3333	0.9402	0.9117	0.[illegible]17	0.4118	0.4276	0.963
12	0.3739	0.3509	0.9385	0.9092	0.4535	0.4123	0.4280	0 963
13	0.3931	0.3682	0.9367	0.9066	0.4552	0.4127	0.4285	0.963
14	0.4125	0.3858	0.9353	0.9045	0.4570	0.4134	0.4289	0.963
15	0.4281	0.3996	0.9334	0.9018	0.4585	0.4135	0.4293	0.964
16	0.4429	0.4143	0.9354	0.9047	0.4599	0.4161	0.4298	0.966
17	0.4526	0.4224	0.9333	0.9016	0.4608	0.4155	0.4300	0.968
Series No. 14.—inclination $\frac{3}{1}$ down-stream. October, 1888. Temperature of water: 9.5° C. (49.1° Fahr.) Weir *I:* Height, 1.133 meter; Length, $l = 1.997$ meter $\left.\right\} \frac{L}{l} = 0.9992.$ Weir *C:* " 0.502 " " " $L = 1.9955$ " $\left.\right\}$								
1	0.0502	0.0512	1.0199	1.0292	0.4485	0.4616	0.4484	1.029
2	0.0629	0.0644	1.0238	1.0351	0.4431	0.4587	0.4422	1.037
3	0.0824	0.0848	1.0291	1.0431	0.4381	0.4570	0.4367	1.046
4	0.0988	0.1019	1.0314	1.0466	0.4356	0.4559	0.4338	1.051
5	0.1220	0.1251	1.0254	1.0375	0.4350	0.4513	0.4308	1.048
6	0.1401	0.1425	1.0171	1.0249	0.4355	0.4463	0 4292	1.040
7	0.1618	0.1641	1.0142	1.0206	0.4366	0.4456	0.4277	1.042
8	0.1796	0.1817	1.0117	1.0168	0.4378	0 4452	0.4269	1.043
9	0.2011	0.2029	1.0090	1.0127	0.4394	0.4450	0.4262	1.044
10	0.2191	0.2207	1.0073	1.0102	0.4410	0.4455	0.4259	1.046
11	0.2382	0.2398	1.0067	1.0093	0.4426	0.4467	0.4258	1.049
12	0.2586	0.2590	1.0015	1.0014	0.4445	0.4451	0 4260	1.045
13	0.2797	0.2795	0.9993	0.9982	0.4465	0.4457	0.4263	1.046
14	0.2975	0.2977	1.0007	1.0002	0.4482	0.4483	0.4266	1.051
15	0.3188	0.3179	0.9972	0.9950	0.4502	0.4479	0.4269	1.049
16	0.3380	0.3360	0.9941	0.9904	0.4520	0.4477	0.4273	1.048
17	0.3589	0.3561	0.9922	0.9875	0.4540	0.4483	0.4277	1.048
18	0.3813	0.3770	0.9887	0.9823	0.4561	0.4480	0.4281	1.046
19	0.3919	0.3877	0.9893	0.9832	0.4573	0.4496	0.4284	1.050
20	0.4043	0.3983	0.9852	0.9771	0.4583	0.4478	0.4287	1.045
21	0.4193	0.4134	0 9859	0.9781	0.4598	0.4497	0.4291	1.048
22	0.4334	0.4255	0.9818	0.9720	0.4611	0.4482	0.4295	1.044
23	0.4468	0.4388	0.9821	0.9725	0.4625	0.4498	0.4298	1.047

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* m_2	Coefficient: for weir *I.* m	Coefficient: for vertical weir 1.13m. high. M	$\frac{m}{M}$
	Meters.	Meters.						
1	0.0392	0.0408	1.0408	1.0618	0.4552	0.4833	0.4568	1.058
2	0.0597	0.0626	1.0486	1.0738	0.4437	0.4764	0.4434	1.074
3	0.0792	0.0828	1.0455	1.0690	0.4385	0.4688	0.4374	1.072
4	0.1020	0.1070	1.0490	1.0744	0.4354	0.4678	0.4333	1.080
5	0.1192	0.1251	1.0495	1.0752	0.4350	0.4677	0.4311	1.085
6	0.1413	0.1475	1.0439	1.0666	0.4358	0.4648	0.4291	1.083
7	0.1596	0.1664	1.0426	1.0646	0.4368	0.4650	0.4278	1.087
8	0.1811	0.1880	1.0381	1.0577	0.4383	0.4636	0.4269	1.086
9	0.1996	0.2072	1.0381	1.0577	0.4398	0.4652	0.4262	1.092
10	0.2194	0.2254	1.0273	1.0412	0.4414	0.4596	0.4259	1.079
11	0.2392	0.2468	1.0318	1.0481	0.4433	0.4646	0.4258	1.091
12	0.2604	0.2672	1.0261	1.0394	0.4452	0.4627	0.4260	1.086
13	0.2800	0.2878	1.0279	1.0421	0.4473	0.4661	0.4263	1.093
14	0.3000	0.3077	1.0257	1.0388	0.4492	0.4666	0.4266	1.094
15	0.3191	0.3260	1.0216	1.0326	0.4510	0.4657	0.4269	1.091
16	0.3387	0.3443	1.0165	1.0249	0.4528	0.4641	0.4273	1.086
17	0.3605	0.3665	1.0166	1.0250	0.4551	0.4665	0.4277	1.091
18	0.3788	0.3837	1.0129	1.0194	0.4568	0.4657	0.4281	1.088
19	0.3974	0.4026	1.0131	1.0197	0.4588	0.4678	0.4285	1.092
20	0.4172	0.4194	1.0053	1.0080	0.4604	0.4641	0.4290	1.082
21	0.4287	0.4310	1.0054	1.0081	0.4617	0.4654	0.4293	1.084
22	0.4439	0.4446	1.0016	1.0024	0.4631	0.4642	0.4298	1.080

Series No. 15.—inclination $\frac{3}{2}$ down-stream. october, 1888.

Temperature of water: 11° C. (51.8° Fahr.)

Weir *I:* Height, 1.133 meter; Length, $l = 1.996$ meter
Weir *C:* " 0.502 " " $L = 1.996$ " $\Big\} \frac{L}{l} = 1.$

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* m_2	Coefficient: for weir *I.* m	Coefficient: for vertical weir 1.13m. high. M	$\frac{m}{M}$
	Meters.	Meters.						
1	0.0421	0.0442	1.0499	1.0758	0.4530	0.4873	0.4543	1.073
2	0.0631	0.0665	1.0539	1.0819	0.4425	0.4787	0.4422	1.083
3	0.0829	0.0885	1.0676	1.1031	0.4374	0.4825	0.4366	1.105
4	0.1029	0.1095	1.0641	1.0977	0.4352	0.4777	0.4332	1.103
5	0.1220	0.1304	1.0689	1.1051	0.4351	0.4808	0.4308	1.116
6	0.1419	0.1502	1.0585	1.0890	0.4359	0.4747	0.4290	1.107
7	0.1614	0.1715	1.0626	1.0954	0.4371	0.4788	0.4277	1.119
8	0.1823	0.1929	1.0581	1.0884	0.4386	0.4774	0.4268	1.119
9	0.1993	0.2098	1.0527	1.0801	0.4400	0.4752	0.4262	1.115
10	0.2218	0.2327	1.0491	1 0745	0.4419	0.4748	0.4259	1.115
11	0.2391	0.2502	1.0464	1.0704	0.4436	0.4748	0.4258	1.115
12	0.2603	0.2718	1.0442	1.0670	0.4457	0.4756	0.4260	1.116
13	0.2782	0.2905	1.0442	1.0670	0.4475	0.4775	0.4263	1.120
14	0.3007	0.3124	1.0389	1.0589	0.4496	0.4761	0.4266	1.116
15	0.3183	0.3308	1.0393	1.0595	0.4515	0.4784	0.4269	1.121
16	0.3414	0.3527	0.0331	1.0501	1.4537	0.4764	0.4273	1.115
17	0.3588	0.3706	1.0329	1.0498	0.4555	0.4782	0.4277	1.118
18	0.3806	0.3914	1.0284	1.0429	0.4576	0.4772	0.4281	1.115
19	0.3985	0.4085	1.0251	1.0379	0.4594	0.4768	0.4286	1.112
20	0.4183	0.4282	1.0237	1.0358	0.4614	0.4779	0.4290	1.114
21	0.4370	0.4447	1.0176	1.0265	0.4631	0.4754	0.4296	1.107
22	0.4496	0.4591	1.0211	1.0318	0.4645	0.4792	0.4299	1.115

Series No. 16.—inclination 45° down-stream. october, 1888.

Temperature of water: 17.5° C. (63.5° Fahr.)

Weir *I:* Height, 1.132 meter; Length, $l = 1.996$ meter $\left\{\frac{L}{l} = 1.\right.$
Weir *C:* " 0.502 " " $L = 1.996$ "

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* m_2	Coefficient: for weir *I.* m	Coefficient: for vertical weir 1.13m. high. M	$\frac{m}{M}$
Series No. 17.—inclination $\frac{1}{2}$ down-stream. november, 1888.								
Temperature of water: 9.5° C. (49.1° Fahr.)								
Weir *I:* Height, 1.137 meter; Length, $l = 1.994$ meter. Weir *C:* " 0.502 " " $L = 1.9965$ " $\frac{L}{l} = 1.0013$.								
	Meter.	Meter.						
1	0.0649	0.0699	1.0770	1.1192	0.4414	0.4940	0.4415	1.119
2	0.0838	0.0904	1.0788	1.1220	0.4370	0.4903	0.4364	1.124
3	0.1026	0.1111	1.0828	1.1281	0.4352	0.4910	0.4332	1.133
4	0.1241	0.1338	1.0782	1.1210	0.4352	0.4879	0.4306	1.133
5	0.1418	0.1531	1.0797	1.1234	0.4361	0.4899	0.4291	1.142
6	0.1645	0.1763	1.0717	1.1109	0.4374	0.4859	0.4276	1.136
7	0.1831	0.1957	1.0688	1.1064	0.4389	0.4856	0.4268	1.138
8	0.2031	0.2168	1.0675	1.1044	0.4406	0.4866	0.4261	1.142
9	0.2224	0.2355	1.0589	1.0911	0.4422	0.4825	0.4259	1.133
10	0.2418	0.2550	1.0546	1.0844	0.4441	0.4816	0.4258	1.131
11	0.2601	0.2747	1.0561	1.0867	0.4460	0.4847	0.4260	1.138
12	0.2823	0.2968	1.0514	1.0795	0.4481	0.4837	0.4263	1.135
13	0.3002	0.3155	1.0510	1.0789	0.4500	0.4855	0.4266	1.138
14	0.3218	0.3368	1.0466	1.0721	0.4521	0.4847	0.4269	1.135
15	0.3395	0.3553	1.0465	1.0719	0.4539	0.4865	0.4273	1.139
16	0.3611	0.3782	1.0474	1.0733	0.4562	0.4896	0.4277	1.145
17	0.3782	0.3925	1.0378	1.0586	0.4578	0.4846	0.4281	1.132
18	0.3975	0.4140	1.0415	1.0643	0.4599	0.4895	0.4286	1.142
19	0.4209	0.4359	1.0356	1.0552	0.4622	0.4877	0.4291	1.137
20	0.4377	0.4536	1.0363	1.0563	0.4640	0.4901	0.4296	1.141

NOTES AND COMMUNICATIONS.

A LARGE LAND-SLIDE.

By Emile Low, Active Member of the Club.

Read January 2, 1892.

As a matter of information merely, the following description of a large land-slide, which occurred some two years ago on the line of the Clinch Valley Division of the Norfolk and Western Railroad (which at that time was under construction), in Southwest Virginia, may prove of some interest.

The cut in which this slide happened lies between the Crossings Nos. 9 and 10 of the Clinch River, which crossings are now known, since the operation of the railroad, as Bridges Nos. 1338 and 1339 respectively.

The cut in question is also a short distance, about a quarter of a mile, west of Pounding Mill Station, which latter is about 30 miles west from Graham Junction, on the New River Division of the same system of railroad.

The accompanying topographical map and profile shows the point clearly where the slide came in. The line of the railroad across the small hill or knoll, between the two river crossings, lies in a through cut—the same being also on a tangent. The cut is 543 feet long between the grade points. The deepest cutting along the center line was a trifle over fifty (50) feet, somewhat more on the upper, and a little less on the lower side, the ground falling but slightly transversely to the axis of the railroad line.

It was intended at one time to pierce this point with a tunnel (as was done at a similar place a short distance west) instead of making an open excavation or cut, but the unfavorable material precluded this. Had the ground proved favorable for a tunnel, the cost would not have varied much, as at the prices paid an open cut of 50 feet in depth about balanced the cost of a tunnel.

Although about sixty (60) per cent. of the excavated material was solid limestone, yet it was overlaid with a stratum of earth and loose rock, which would not have afforded a suitable and desirable tunnel roof, necessitating, in this special case, permanent timbering or arching.

The limestone also lay at quite an angle, the inclination being about 45 degrees, the dip being from north to south nearly, and this made the line of cleavage about parallel with the axis of the railroad line. In consequence of this the lower side of the cut stood at a greater or steeper slope, while the upper one was much flatter. The limestone occurred also in layers, the laminations being about 2 feet thick on an average.

The material from the cut was excavated by the contractor in the manner usual on railroad work, namely, by hand-drilling and blasting, the broken-up and loosened material being removed by horses and carts, which were also loaded by hand.

As can readily be seen by the map and profile, the haul at each end of the cut was quite short. As the material was not all needed in the adjacent embankments, much of it had to be wasted, although such as was suitable was piled up and afterwards utilized ballasting the road-bed.

The amount of material taken from the cut by the contractor before the occurrence of the slide was close on to 28,000 cubic yards.

Work in the cut was started late in the autumn of 1887, and only moderate progress was made, as there were no exigencies requiring great haste. The greatest quantity moved in any one month at one end was about 2,500 cubic yards.

The cut was dressed up in good shape, and the track laid through it about the latter end of May, 1889.

On the completion of the cut there were no visible indications of any tendency to slide or slip. In fact, it was the last place along the whole line where anything of this kind was looked for.

On the night of Saturday, May 25, 1889, considerable rain fell, and early the next morning the slip occurred. It will be remembered that about this time considerable wet weather was experienced in every part of the country—it being just before the memorable Johnstown flood. The material all came in from the north side. It was first brought to the writer's attention after dinner of that day, when in company with a party of friends he was taking an afternoon ride along the line of the completed railroad grade. The track for about one-half a mile west of the slide is on a tangent, and on this part is located the tunnel, about 155 feet in length, to which reference is made in the first part of this paper. Upon coming suddenly upon this tangent from the west, and looking up the same, some familiar points on its east end could not be discerned. Further investigation showed that there was some obstruction on it, of an unknown nature—the view being somewhat obscured by the tunnel which was between. Placing his horse in charge of one of the party, the writer made his way hastily up the track, while the others rode around.

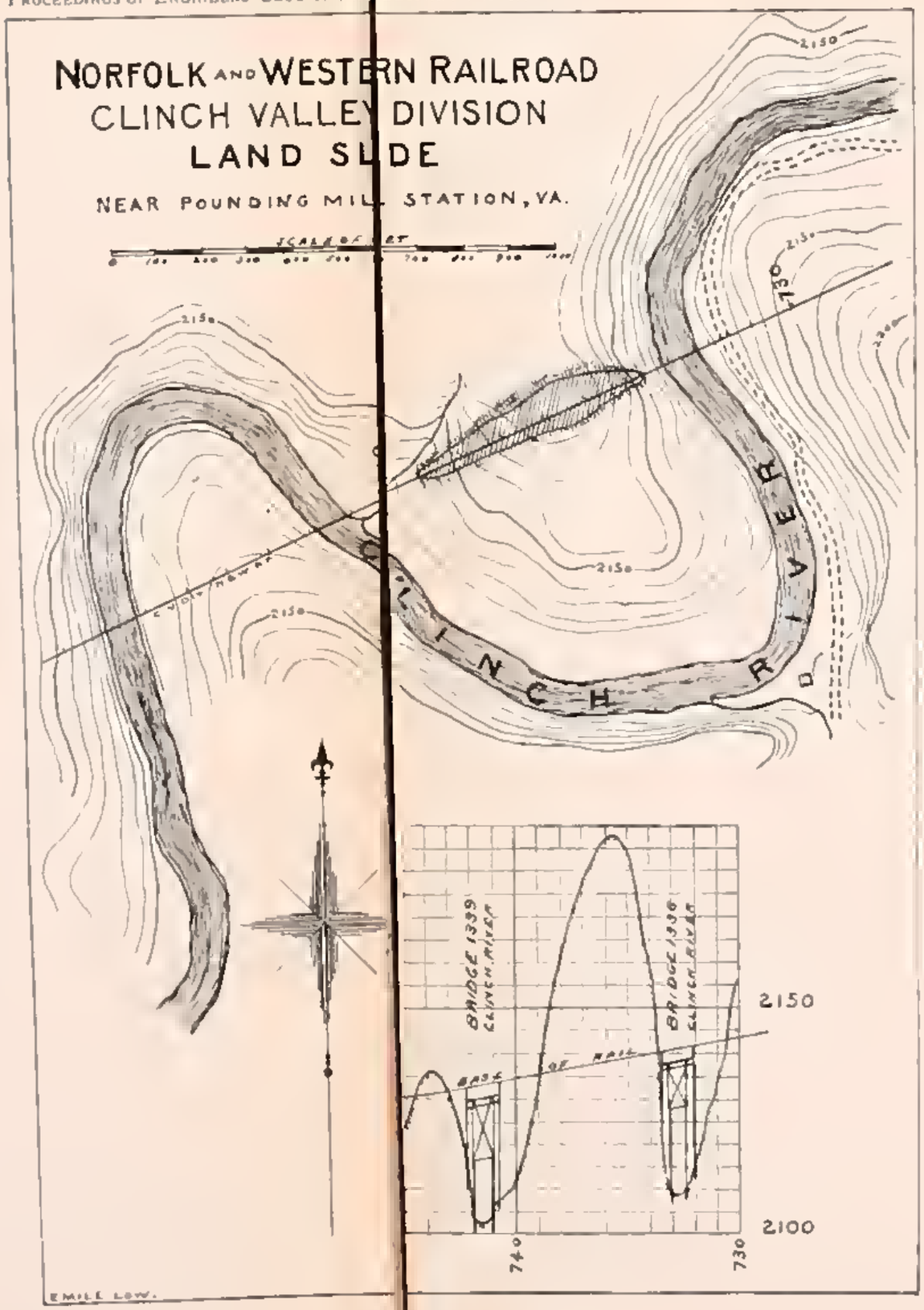
Upon coming close to the cut he noticed what had happened. About 400 lineal feet of the railroad track were covered to an average depth of over 20 feet with rock and earth intermixed. A hasty calculation showed that about 6,000 cubic yards of material had slipped in, the removal of which, in the confined space which it occupied, would consume considerable time. Immediate arrangements were made with the contractor to prosecute this work with the greatest energy.

The slide had interfered with the track-laying, and it was therefore important to remove the slide at once, as no more track could be laid until the obstacle interfering with its progress was taken away. Day and night forces were organized with dispatch, each consisting of about fifty men, in charge of suitable superintendents and foremen.

The railroad track at the west end was torn up, and in its stead two narrow-gauge tracks were laid, which turned in opposite directions just before the Bridge No. 1,339 was reached. The ordinary contractor's dump-cars were used on these tracks—the cars being of about one cubic yard capacity.

Three derricks, such as are used in laying masonry, were also placed close to the edge of the cut, on top—two of them on the south side and the other one on the north side. The former were worked by means of a steam-hoisting-engine, belonging to a firm of trestle and bridge contractors, who were engaged near by. Suitable wooden boxes were made, heavily reinforced with iron at the corners and elsewhere, into which the material was loaded, then hoisted and dumped over the lower side of the cut.

The other derrick was manned by hand. The force of men, under the immediate direction of the company's track-laying foreman, was also placed at work, with wheel-


NORFOLK AND WESTERN RAILROAD
CLINCH VALLEY DIVISION
LAND SLIDE
NEAR POUNDING MILL STATION, VA.
SCALE OF FT
CLINCH RIVER
2150
730
BRIDGE 1339 CLINCH RIVER
BRIDGE 1336 CLINCH RIVER
BASE OF RAIL
2150
2100
740
730
EMILE LOW.

barrows, in the east end of the cut, loading material on to flat cars. Five different forces were thus kept at work incessantly—one at each end of the cut and three on top. As much of the material consisted of large slabs of limestone, considerable blasting had to be resorted to, the rocks being too large to handle. Work was kept going day and night, with some little interruption from rain.

By July 3d the entire slip had been removed, and track-laying was resumed the following day, July 4th.

One factor which somewhat retarded the progress of the work, was the narrowness of the cut, which was only 14 feet wide at sub-grade, with slopes of ¼ to 1 for the lower 10 feet—on this account but one car could be loaded at the face of the cut at one time.

The position of the fallen rocks, which were also inextricably mixed, caused delay, as all of them had to be block-holed—an operation consuming much time. The cost of the removal of the slide was not far from $6,500.

No rational explanation of its movement can be assigned, unless it be that there was an enormous "mud seam" between two layers of stone, and extending from one end of the cut to the other. The toe having been cut away, it is likely that the weight of the superincumbent material overcame the frictional resistance and thus slid in.

DISCUSSION.

Mr. E. V. d'Invilliers:—It appears to me that the cause of this slide is not far to seek. In the region referred to, with which I am very familiar, land-slides are of frequent occurrence, and are due to the geological structure of the region. The formations are badly faulted, strata 2,000 feet apart geologically being found in close contact. This faulting gives rise to abnormal cleavage, with segregation of clay bands to an extent not found under other circumstances.

To the west of the locality referred to, on the Louisville and Nashville Railroad, and on the further side of the Alleghany escarpment, an enormous slide occurred in rocks of a totally different character, but similarly faulted. The ground was practically solid, and its appearance gave no cause for fearing a slide. Nevertheless, a slide occurred which cut off communication for several days, and the removal of which entailed a much greater expense than in the case described in Mr. Low's paper.

EFFECT OF HEATING AND HEADING WROUGHT-IRON BARS.

By H. W. Spangler.

Read December 19, 1891.

Sometime since it was suggested that a series of tests be made on commercially made bolts and rods upset for threading, to determine the effect of heating without working, and the effect of working the iron in heading and upsetting on the strength of the bars. One of the large manufacturing concerns furnished the material for making the tests, and did all the work on them under the direction of Mr. John L. Gill, Jr. (Active Member of the Club), who planned and superintended the preparing of the bars.

Ten bars of commercial $\frac{3}{4}$-round iron were taken and cut into lengths of about 16 inches, making 80 pieces in all. The bars were numbered from 1 to 10, and the successive pieces from each bar were marked with the successive letters of the alphabet in addition to the number of the bar from which they were cut. The bars of the first set were tested as they came from the mill. This set was marked 1A, 2A, 3A, etc. The second set marked 1B, 2B, etc., were annealed from a cherry-red before being tested; or perhaps it would be better to say that they were cooled from a heat below welding heat.

The bars of the set marked 1C, 2C, 3C, etc., were heated hot enough to weld and allowed to cool on the floor before being tested.

The set marked 1D, 2D, 3D, etc., were upset in the machine, the upset portion measuring $2\frac{1}{2}$ inches long and 15-16 inch in diameter, and allowed to cool on the floor before being tested.

The set marked 1E, 2E, 3E, etc., had ends welded on before testing. These ends, when finished, measured about 1 inch in diameter and 5 inches long.

The set marked 1F, 2F, 3F, etc., were cut into two parts at the middle of their length and the parts were then welded together.

The set from 1G to 5G, both inclusive, were cut as in the last lot, and after being welded the bars were anealed, or uniformly heated and cooled.

The set marked 6G to 10G had heads made on them in the machine, and were struck sharply with a hammer while in the testing machine, and loaded. The heads were $1\frac{1}{4}$ inches across flats and $\frac{1}{2}$-inch thick.

The set marked 1H, 2H, 3H, etc., were headed in the machine as in the last lot, and were then pulled.

The bars that were annealed were heated to a cherry-red in an oil fire and allowed to cool.

The bars that were heated to a welding heat were heated white hot in an oil fire and allowed to cool on the floor.

The bars that were upset and headed were heated in an oil furnace and upset or headed on a machine which was large enough to handle $1\frac{1}{4}$-inch stock.

The pieces that were cut and welded were heated in a blacksmith's coal-fire.

All the work was done in the same manner, and with the same care, and no more, that would be exercised in filling any order for the same class of material.

The material was all commercial $\frac{3}{4}$-inch round iron, .435 square inch in area, and varying from 2.3 per cent. above to 1.4 per cent. below that in area. The yield point, or what is usually taken as the elastic limit, varied from 32,854 to 38,470 pounds per square inch, with a mean of 34,545 pounds. The breaking load varied from 48,923 to 58,941 pounds per square inch of original area with a mean of 51,097. The percentage of elongation in 8 inches varied from 15.9 to 25.6, with a mean of 21.9.

The various tables show in detail the values of the yield point, breaking load and elongation in 8 inches. The loads are reduced to one square inch of original area, and the elongation was, whenever possible, measured for 4 inches on each side of the break, marks having been made on the bars before testing at each inch of their length.

Table II. shows the mean of the results, together with the maximum and minimum values, and shows clearly the effect of the different methods of treating the material, as far as the number of specimens tested can do so.

Taking first the plain bar, heating one part to a cherry-red reduced the average, maximum and minimum elastic limits, and heating the next piece to a welding heat made the elastic limits still lower, but not to the same extent as the first heating. The breaking load was reduced to a greater extent than after the first heating. The elongation increased by heating, but the pieces which were heated to a welding heat and then allowed to cool, improved in this respect quite as much as the pieces that were heated to a cherry-red. The effect of heating without working seems to be that which might be expected from the treatment, but the heating, and not the annealing, seems to be the cause of the change.

Taking the next set, those having upset or staved ends, the average elastic limit is something higher than that of the plain bar, the average breaking strength is about 4 per cent. lower, and the average elongation is about 40 per cent. less than in the plain bar. An examination of the pieces will show the reason for at least a part of this difference. All the pieces broke within $1\frac{1}{4}$ inch of the corner, or practically within the grip holding the pieces in the upsetting machine. The grip necessary to hold the piece reduced the section slightly, confining the elongation to a small portion of the bar, and thus reducing the percentage of elongation. The reduced size of the bar, under the upset portions, will account for the reduced breaking load.

The bars with the butts welded on show how little reliability and uniformity are to be obtained on the average work of this class. The elastic limit was not far from that of the plain bar, and the variation in the elastic limit was about the same as is to be found in the first set. The breaking load averaged about 14 per cent. less, and the variation in the breaking load amounted to about 30 per cent. of the mean. The elongation averaged 7.4 per cent. as against 21.9 per cent. of the original bar, and the variation in elongation was from 1.2 to 17.0 per cent.

As compared with the upset ends the welded bars were in every way inferior.

The bars cut in the middle and welded together showed about the same values as the bar with the ends welded on, except that the elastic limit was somewhat lower, but still came within the range of the original pieces.

The annealing of the welded bars has practically no effect, the little difference shown being the reverse of what might be expected from the heating.

The effect of the heading is clearly seen from the fifteen pieces which were finished in that way. The head pulled off in two cases, and was defective in a third, showing that in 20 per cent. of the bolts tested the head was the weakest part. With them all, however, the elastic limit was quite up to that of the original bar, the mean being almost exactly the same, and the variation being very much less. A portion of these bars were struck a sharp blow with the hammer while loaded to about $\frac{9}{10}$ of the elastic limit, and the effect seems to be that the elastic limit and the breaking load were slightly raised and the elongation was slightly decreased.

The general conclusions that can be drawn from the tests are that heating wrought-iron, and allowing it to cool, is of little use with wrought-iron, which has been generally understood, and that heating it to a welding heat and allowing it to cool lessens its tensile strength about 4 per cent.

Upset ends are about as strong as the original bar, although in this case the reduction in area, caused by the gripping of the machine used in making the bars localized the elongation, reducing it to 30 per cent. less than in the case of the original bar.

The welded pieces are all inferior to the original bar, having only about 85 per

cent. of its strength, and the elongation may be reduced to one-third of that of the original bar on the average. In some cases, however, there was practically no elongation, the weld giving way bodily, although showing quite as high an elastic limit as the original bar. Reheating uniformly and allowing to cool, has practically no effect on the welded bar.

Headed bars, without flaws, are as strong as the original bar, but in the samples tested 20 per cent. of the heads were defective.

The machine used was an Olsen, 50,000 pounds, having an automatic small weight, allowing the yield point to be closely determined. The ordinary V-shaped jaws used on round pieces and provided with the machine, were used, there being the usual universal joint behind the V-blocks. The headed pieces were tested by putting the bolt through a hole in a loose cast-iron block, and catching the point of the bolt in the lower V-jaw. The speed at which the work was done was that ordinarily used, about .04 inches extension per minute up to the elastic limit, and .6 inches per minute until the piece broke, these speeds being just about sufficient to keep the small weight constantly moving. The load at the drop of the beam, which is properly the yield point, was read for the elastic limit, and the breaking load here given was the maximum to which the piece was subjected.

The tests were made under my direction by Messrs. Capp, Finn and Head at the University.

TABLE I.

Bar.	AS ROLLED. Mark.	Elas. Limit.	Break. Load.	Elon. %	ANNEALED. Mark.	Elast. Limit.	Break. Load.	Elon. %	WELDING HEAT. Air-cooled. Mark.	Elas. Limit.	Break. Load.	Elon. %	END UPSET. Mark.	Elas. Limit.	Break. Load.	Elon. %		END WELDED ON. Mark.	Elas. Limit.	Break. Load.	Elon. %	
1	A	38,470	50,807	22.5	B	34,848	52,448	25.3	C	32,175	49,312	24.5	D	33,147	49,044	16.3	Broke near head	E	35,159	47,050	6.6	Broke at weld
2	A	33,463	51,872	25.0	B	33,518	50,764	25.0	C	30,413	48,820	25.9	D	33,888	49,907	16.6	"	E	33,649	38,064	3.8	"
3	A	34,038	51,639	17.12	B	34,700	53,581	23.0	C	34,108	51,058	25.9	D	37,490	50,117	15.2	"	E	35,271	37,201	1.2	"
4	A	35,665	53,941	22.6	B	34,581	51,744	25.5	C	31,062	49,639	24.0	D	36,400	50,093	15.6	"	E	36,596	44,641	5.0	"
5	A	33,857	51,688	22.5	B	30,833	50,002	25.6	C	31,359	49,005	21.5	D	35,555	49,583	15.2	"	E	35,846	51,249	17.0	6″ from weld
6	A	36,470	51,831	20.6	B	31,034	50,090	17.5	C	32,584	48,618	18.3	D	35,708	48,652	14.0	"	E	38,537	50,954	16.5	1″ from weld
7	A	34,046	50,091	15.9	B	32,700	50,568	26.0	C	32,157	48,611	24.3	D	37,259	49,477	14.0	"	E	35,548	40,009	4.0	at weld
8	A	33,016	48,923	25.6	B	32,313	49,887	24.5	C	30,569	48,379	28.8	D	34,807	47,134	12.2	"	E	36,668	49,560	11.2	"
9	A	33,150	50,150	25.0	B	32,138	52,184	25.8	C	32,068	49,942	25.5	D	36,131	48,493	15.1	"	E	35,711	37,827	3.0	"
10	A	32,854	49,965	22.3	B	32,900	49,338	26.5	C	30,890	48,220	23.8	D	32,900	45,841		Broke at head	E	32,649	44,650	5.6	"

Bar.	CUT AND WELDED. Mark.	Elas. Limit.	Break. Load.	Elon. %		WELDED AND ANNEALED. Mark.	Elas. Limit.	Break. Load.	Elon. %		HEADED. Struck in Testing Machine. Mark.	Elas. Limit.	Break. Load.	Elon. %		HEADED. Mark.	Elas. Limit.	Break. Load.	Elon. %	
1	F	33,061	36,581	3.4	Broke at weld	G	32,711	41,734	5.0	Broke at weld						H	34,367	51,107	21.0	
2	F	32,631	45,420	7.3		G	32,862	43,385	6.1							H	32,423	50,809	22.3	
3	F	34,503	44,548	5.3		G	35,712	45,967	6.8							H	33,620	52,034	18.9	Broke in grip
4	F	33,829	49,338	10.5		G	33,922	45,687	6.8							H	34,806	51,803	20.3	
5	F	32,932	45,120	7.5		G	34,201	50,184	11.9							H	35,044	41,188		Head pulled off
6	F	32,563	44,972	5.3							G	37,753	51,940	17.2		H	35,032	51,045	20.8	
7	F	31,725	49,249	13.5							G	35,682	44,114		Head defective	H	34,889	50,182	22.4	
8	F	32,745	42,828	6.9							G	34,286	49,592	16.7	"	H	35,214	49,364	20.4	
9	F	31,907	39,913	5.0							G	35,380	50,598	19.6		H	34,990	50,241	21.3	
10	F	33,439	47,114	9.5							G	33,287	51,027	23.4		H		49,449	21.5	

TABLE II.

	Elastic Limit.				Breaking Load.				Elon., per cent.			
	Bars.	Av.	Max.	Min.	Bars.	Av.	Max.	Min.	Bars.	Av.	Max.	Min.
As rolled	10	34,545	38,470	32,854	10	51,097	53,941	48,923	10	21.9	25.6	15.9
Annealed	10	32,957	38,848	30,833	10	51,061	53,581	49,338	10	24.5	26.5	17.5
Welding heat . . .	10	31,738	34,108	30,413	10	49,260	51,058	48,220	10	24.3	28.8	18.3
Upset	10	35,323	37,490	33,147	10	48,834	50,117	47,134	10		16.6	12 2
	9	35,597			9	49,166		45,841	9	14.8		
Welded end	10	35,563	38,537	32,649	10	44,121	51,249	37,201	10	7.4	17.0	1.2
" bar	10	32,939	34,503	31,725	10	44,208	49,338	36,581	10	7.4	13.5	3.4
" and anneal'd	5	33,882	35,712	32,711	5	45,451	50,484	41,734	5	7.3	11.9	5.0
Headed	4	35,176	37,753	33,287	4	50,782	51,910	49,592	4	19.2	23.1	16.7
"	9	34,484	35,214	32,423	10	49,719	52,034	41,188	9	20.9	22.1	18.9
. . . . .	7	34,532			8	50,496		49,346	8	21.2		

THE PROPOSED BOULEVARD FOR PHILADELPHIA AND ITS APPROXIMATE COST.

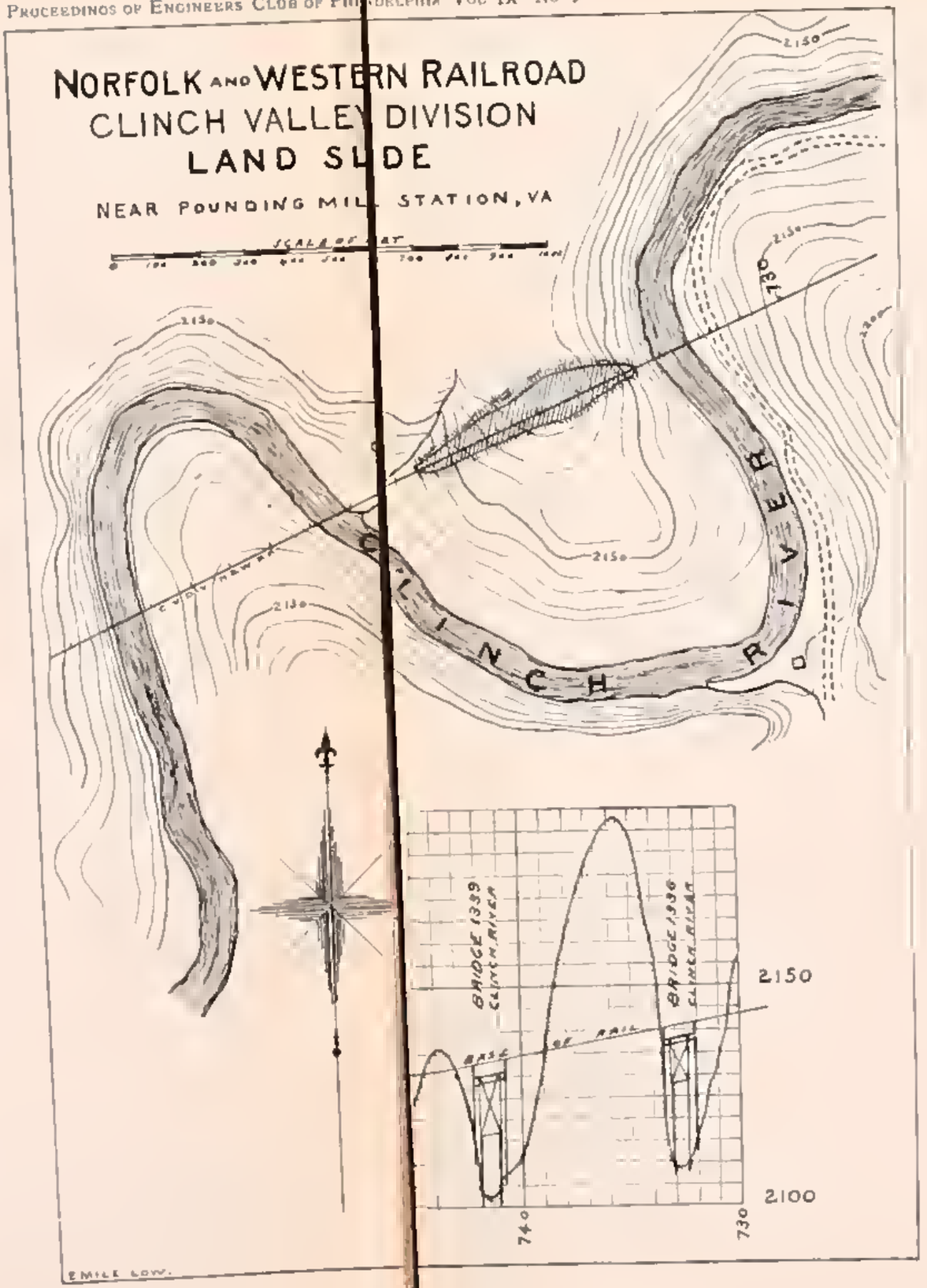
By W. W. Thayer, Active Member of the Club.

Read December 19, 1891.

In the early part of this year a number of influential gentlemen annexed their names to a petition to the Councils of Philadelphia, embodying the placing on the city plan from Penn Square or City Hall to the Green Street entrance of Fairmount Park or thereabouts, an avenue with a minimum width of 150 feet. This petition, coming then before the Board of Surveyors, was referred to a sub-committee for report on advisability of adoption and approximate location, together with what other information it could collect.

This committee prepared plans on which were shown all properties affected by the opening of such an avenue, and the assessed valuation of each, taken from the official Assessors' lists on file in that Department. Various lines were tried on this plan, economy as well as the preservation of important and costly buildings being sought, and a straight avenue finally adopted from Broad and Filbert Streets to the proximity of Twenty-fifth and Spring Garden Streets. This plan, with the accompanying report and suggested ordinance, was unanimously approved by the Board of Surveyors and forwarded to the Survey Committee of Councils, who, on September 29, 1891, with a favorable recommendation, forwarded it to Councils. Councils again, after a long debate, referred the whole matter back to the Department of Public Works for further information and estimate, or, in other words, sent it back again to the beginning of its course.

We then had the Boulevard in its first tangible form, that is, in the form of an Ordinance before Councils to place it on the city plan.


NORFOLK AND WESTERN RAILROAD
CLINCH VALLEY DIVISION
LAND SLIDE
NEAR POUNDING MILL STATION, VA
SCALE OF FEET
CLINCH RIVER
2150
2130
730
740
BRIDGE 1339 CLINCH RIVER
BRIDGE 1336 CLINCH RIVER
BASE
EMILE LOW.

The scheme for this avenue to the Park is an old one revived; there are extant sketches of such an avenue over twenty years old; but a great deal of credit is undoubtedly due to Mr. C. K. Landis, Civil Engineer, who, as far as I can find, was the first to prepare intelligible plans showing a location of an avenue and the buildings affected by it. Mr. Landis must have given a great deal of time and study to the scheme, as the records show, but from some reason or other, most likely the stagnation of municipal enterprise or the want of support of the press, the idea lapsed into the somnambulistic state that municipal improvements are wont to take in this city, when the question of money is advanced. The support of the press is undoubtedly essential to such an undertaking, and without it, I think such a scheme might at once be considered a lost cause.

The line as approximately located, as will be seen by a glance at the sketch, allows the most important and costly structures to remain, namely: The Broad Street Station is left siding on it, the new Friends' School can be bodily swung so as to front on it, the Roman Catholic Cathedral of St. Peter and St. Paul is given frontage on it, the Wills' Eye Hospital and the Academy of Natural Sciences will front on the open gardens around it. The Livingston Public School, with slight alterations, can be made to face it, while the open space created by the demolition of the worsted mills at Twenth-fifth and Spring Garden Streets will afford a plaza, the center of which would be a most imposing site for the Washington Monument of "The Society of the Cincinnati," which is to be erected somewhere in this city, and a portion of which is now in Fairmount Park. The reservoir, immediately back of the monument, when planted out properly, will afford a most beautiful and appropriate background of green.

The cross-section that I would urge, in order to make out of it a Boulevard and not a street, is one which resembles somewhat that of the Champs Elysées of Paris. I give here the section adapted for 150 feet and one adapted for 160 feet. This section has been approved by the Board of Surveys as a portion of the plan approved by them. The section for 160 feet is far preferable, and should be strongly advocated, as by it sufficient room is allowed for all the parts of the Boulevard. A sidewalk of 12 feet for pedestrians, with building restrictions of 3 feet, is ample for the travel necessary for the ingress and regress to buildings. A cartway of 20 feet of Belgian blocks will allow ample facilities for the entrance of wagons to the houses, even if a car-track is laid along one side of it, and a pedestrian path of 12 feet (asphalt) with 5 feet of grass, on either side of which should be planted trees, will afford, in time, a most beautiful walk of one mile.

The driveway or main Boulevard in the center, with a clearance of 52 feet, when properly paved, curbed, drained and lined with trees, will make an avenue of which Philadelphia may well be proud.

The other half section is identical with the one just described and makes a symmetrical section, with provisions for room for all parts of the Boulevard. The main driveway of asphalt and Macadam should never be disturbed when once laid, as it is impossible practically to patch such a roadway and yet retain the original crowning surface. For this reason I would suggest that all sewers, pipes, drains, conduits, etc., be laid under the Belgian block pavement. The Boulevard should end at Twenty-fourth Street, and the grand open plaza be constructed at the intersection of these three streets, namely, Spring Garden (120 feet wide), Twenty-fifth Street (144

feet wide), and the Boulevard (160 feet wide). How grand would be the intersection of three such streets when properly laid out, with a handsome avenue stretching away to the southeast and Fairmount Park on its northwest!

The Boulevard should be built on a straight line, for many reasons. It is cheaper. The presence of curved lines tends to cut up the adjoining properties and lose valuable room. The shortest distance is the most economical, not only for construction but for maintenance. A view of either statue from the far end would be lost by curved lines. The perspective effect of distances is only gained by straight lines with curved corners, and, lastly, we have learned by experience that curves in Boulevards, though beautiful on paper, destroy the end in view, namely, the effect on the eye of the whole work.

The cost of the condemnation of properties necessary for the construction of such a work is rather hard to estimate, as the award of juries is most uncertain, as well as the error which may be incurred by assuming assessed valuations. By consultation, however, with authorities on the subject, I am informed the assessed valuation of properties in this locality is about 75 per cent. below their actual value. In my estimate below, therefore, I have assumed a basis of 90 per cent., endeavoring to be on the safe side throughout. The other valuations are taken from the scales of prices now in vogue.

I have worked the estimate up in quantities by calculation, but refrain from giving them here for professional reasons.

Sewers should be not smaller than 2 x 3 and egg-shaped, and inlets placed at the proper places. The grades would all be light and the warping of the road-bed by its diagonal crossing with streets on a grade could be easily overcome by a slight revision of the grades of such streets.

From the fact that to preserve the Boulevard heavy travel will have to be kept off the main driveway, a good Macadam pavement is preferable to asphalt. Such a drive, when properly laid, is easier and safer to ride on, affording good foothold for horses, healthy, self-draining and not so sensitive to the changes of climate prevalent here. At the price I have quoted below a fine Macadam roadway can be constructed under the most improved designs and specifications. The trees along the grass plots should be planted diagonally opposite each other, as shown in the accompanying sketch, so as to allow as much room as possible for their expansion in growth.

From Twenty-fourth Street westward should be the grand plaza, its sides laid out in walks and gardens and the whole center thrown into a drive as an approach to the Washington Monument, which is very high and over 90 feet square and should have a large space adjoining it, if only for the purpose of viewing it. Electric lamp-posts should be placed along the edge of the drive, instead of the gallows-post now in vogue, and the drive, when finished, thrown into the jurisdiction of Fairmount Park, and the Park police, superintendence and maintenance extended thereto.

ESTIMATE OF $1\frac{1}{16}$-MILE BOULEVARD FROM CITY HALL TO FAIRMOUNT PARK, ACCORDING TO SECTION ATTACHED OF 150 FEET.

Assessed valuation of property to be condemned and taken by the City of Philadelphia	$2,960,000 00
Add 90 per cent., as above stated	2,664,000 00
Cost of property to be condemned	$5,624,000 00

Main driveway (Macadam)	$32,223 00	
" " Intersections	3,300 00	
" " Plaza	1,000 00	
Cartways (block)	51,498 00	
Intersections	4,250 00	
Walks (pedestrian)	14,419 60	
Sidewalks (brick)	9,989 50	
Repairs to sidewalks	850 00	
Grass plots (grass sod)	1,956 00	
Granite curb, 8″	34,500 00	
Garden curb	13,500 00	
Return curbs, etc.	3,250 00	
Sewers and drain-pipes	24,000 00	
Trees	14,400 00	
Crossing-stone set	1,800 00	
Sewer inlets (drop comp.)	12,000 00	
Excavation (all material)	5,000 00	
Electric lights	11,025 00	
Laying wires (underground)	3,500 00	
Tearing down present buildings	10,000 00	
Surveys by Dept. of Surveys	10,000 00	
Other city charges	3,000 00	
	$265,461 10	
Add 10 per cent. for emergencies	26,546 11	
		$292,007 21
Actual cost of Boulevard, complete		$5,916,007 21
The main drive, constructed of asphaltum, would cost	$82,000 00	
The sidewalks, if paved with asphaltum, instead of brick, would cost about	21,153 00	
Total	$103,153 00	
Deduct estimated cost of Macadam and brick	45,512 50	
	$57,640 50	
Thus adding to my original estimate of construction		57,640 50
And making the total cost of Boulevard, complete		$5,979,411 76

I give these figures for those who disagree with me on the advisability of the Macadam roadway.

In this estimate I have not taken into account anything that would decrease in any way the actual cost—such as the re-selling of lots fronting the Boulevard, increased taxation, etc., etc., which, in my opinion, would amount to nearly $650,000—but have endeavored to give an estimate without any uncertainties.

If we could only picture the completion of such a work, rather than seek out some way of getting it built, how different would be our opinions—a long, straight avenue of over a mile in length, stretching away to the northwest, lined with a double row of handsome trees and thronged with carriages and pedestrians; the gateway to the

renowned Fairmount Park, with the statue of Washington at one end, facing that of William Penn at the other; the City Hall rearing its high tower in full view from every part of the avenue, with handsome buildings, such as the Masonic Temple, the Academy of Natural Sciences, the Pennsylvania Railroad Station, the Cathedral, etc., fronting on the avenue; a drive for the horseman, a short cut for the business-man, an outing-place for the poor man, and, above all, a great addition to the beauty and reputation of our city.

DISCUSSION.

Professor L. M. Haupt remarked that projects for a Boulevard to connect Fairmount Park with the vicinity of Broad and Market Streets had been proposed and discussed more than twenty years ago, and proceeded to sketch briefly the history of the subject.

In 1869–70 a club was organized among the Park Engineers, and called the Essay Club; and one of the first subjects discussed by him before this club was a proposition for such an avenue. It was admitted on all hands that a better approach to the Park was needed, and the project was heartily endorsed by the Park Commissioners, of which Gen. George Meade was President, and Mr. George M. Cresson, Chief Engineer.

It was recognized that the tracks of the Reading Railroad Company should be depressed in order that such a boulevard could properly reach the Park, and the Reading Railroad Company was waited upon, but without results. This railroad still remains a problem to be solved in connection with any such scheme, for the dangerous crossings should be obliterated by shifting the line northward, to pass under Hamilton Street.

At the present time there are three plans under consideration, one of which corresponds closely with that proposed in Mr. Thayer's paper. In a second plan, the avenue extends from the north front of the Public Buildings, at Broad and Filbert Streets, to a junction with Pennsylvania Avenue at Twenty-first Street. This route, being shorter, and therefore cheaper by about one-third, Professor Haupt preferred to the one described by Mr. Thayer. From Twenty-first Street northwestward, the present line of Pennsylvania Avenue, which contains the Reading Railroad tracks, should be utilized. The avenue would have to be widened; but this would be inexpensive, as the buildings upon the property adjoining it are of comparatively little value.

The principal objection to the route now exhibited is the appearance of the blank wall of the Fairmount reservoir at the northwestern end of the avenue, though this would be to some extent relieved by the monument which it is proposed to place immediately in front of it.

Professor Haupt had discussed this matter, together with the construction of other diagonal avenues, in the Club Proceedings in 1883, and in the *Franklin Institute Journal* of April, 1877.

Mr. Thayer's estimate of the cost shows, of course, but one side of the account. It omits entirely the vast benefits which would accrue to the city from the construction of the avenue, and which, it is believed, would outweigh the expense.

The avenue would displace about 3 per cent. of the population of the large area of which it forms the diagonal; but, on the other hand, it would increase the available frontage by about 12 per cent. So far, therefore, from driving population from the city into the rural districts, it would, on the contrary, increase the accommodations for them within the built-up portion.

ROOM 18, 4TH FLOOR
POST OFFICE BUILDING,
PHILADELPHIA

PROCEEDINGS

OF THE

ENGINEERS' CLUB OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

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XVI.

EVAPORATION BY MULTIPLE EFFECT.

BY TEILE HENRY MÜLLER, Active Member of the Club.

Read May 21, 1892.

THE formation of vapors from water or other volatile substances is practiced in engineering and manufacturing establishments for two very distinct purposes, and may be classified accordingly, as follows:

First.—The vapors are utilized—

(*a*) Under pressure and used as vapors, as in steam boilers.

(*b*) Under more or less pressure, but utilized only when again condensed to a liquid, as in the various forms of distilling apparatus.

Second.—The vapors are rejected, and the remaining liquid or dry residuum is utilized, as in evaporators.

EVAPORATORS.

Apparatus of the latter class may be subdivided, according to the manner in which the process of evaporation is performed.

(*c*) Evaporation at temperatures below the boiling point of the liquid, but in contact with the atmosphere.

Here evaporation takes place at the surface of the liquid, and is produced by the more or less dry air above, as in the natural evaporation of water in lakes, ponds, damp earth, etc.

This form of evaporation is very seldom used for manufacturing purposes.

(*d*) Evaporation at a temperature below the boiling point of the liquid, by means of a more or less heated current of air produced by mechanical means.

(*e*) Evaporation at the boiling point under atmospheric pressure, either by the direct action of the furnace, or by steam, or by heated air forced through the hot liquid.

(*f*) Evaporation in vacuum.

(*g*) Evaporation by multiple effect.

These different methods of evaporation are employed in manufacturing establishments according to the character of the goods produced; but from a purely engineering standpoint one cannot help being surprised by the close analogy between the evolution of the evaporating apparatus and that of the steam-engine. As we have in the steam-engine first the old atmospheric engine, then the Watt condensing, and, lastly, the modern high-class condensing engine, using the steam expansively; so we have in the evaporation, first, the old open kettle, then the vacuum pan, and, lastly, the multiple-effect evaporating apparatus, which also uses steam expansively and employs condensation.

Indeed, it may be questioned, from the standpoint of the political economist, whether the practice of using steam expansively in a steam-engine, or the application of this same expansion of steam in evaporators, is of the greater importance to the preservation of our stock of fuel.

The application of condensation and expansion to evaporating apparatus has made it possible to effect, at least, a very large percentage of evaporation by the exhaust steam from the steam-engine. Hence the cost of effecting such evaporation frequently represents only the difference of cost of operation between a non-condensing cut-off engine and a condensing engine.

Statistical data representing the total amount of evaporation to be effected per annum in the different processes of manufacture are not easily obtained, because often no records are kept.

A few instances may be sufficient. The total quantity of sugar produced in the year 1888, and in the season of 1888–89, was, in round numbers, 5,036,000 tons, of which about 2,371,000 tons were cane sugar, and 2,665,000 tons beet sugars.

The effect of improved evaporators on this industry can readily be judged by the fact that the entire evaporation of the cane sugar is performed with the refuse of the cane as fuel, and in the central beet factories the fuel will not much exceed 1.1 pounds of coal per 1 pound of sugar.

I have not the figures of the last census at hand, but in 1880, the production of soda and soda ash in the United States had already reached 40,259,938 pounds, and that of salt amounted to 29,805,298 bushels. These quantities have largely increased, and new industries, requiring considerable evaporation, have been developed during the last decade, so that we may safely place the subject of evaporation, in point of importance, next to the production of steam for power. To-day, more than one industry depends for its very existence solely upon the possibility of cheap evaporation.

Evaporation in Contact with the Atmosphere at Temperatures below Boiling Point.

This is a very wasteful process, for the amount of heat required to evaporate a pound of water under these conditions is considerably greater than when the temperature is raised to the boiling point.

Peclet gives the quantities of heat required to evaporate 1 kilo water at

20°	Centigrade.	1,370	Calories.
30°	"	1,160	"
40°	"	1,070	"
50°	"	840	"
60°	"	760	"
70°	"	720	"
80°	"	690	"
90°	"	660	"

Water evaporated at 20° Celsius requires 1,370 calories per kilo, while if evaporated at boiling point it would require 80 calories to bring the water to 100°, and 555 to vaporize or 615 calories, or less than one-half of the heat required at the lower temperature.

To describe the different methods employed to effect this method of evaporation would take up the entire evening; as a

representative process, I will mention here the extensive brush-works erected for preliminary concentrating of salt solutions pumped from the wells, before they go to the evaporating pans.

Evaporation at the Boiling Point and Under Atmospheric Pressure.

This is the process most frequently employed in chemical works, where the quantities to be operated on are not very large or of such qualities that a continuous process cannot very easily be employed; or, where a special manipulation of the material under process is required during the process of evaporation; and last, but not least, where it is desired to keep the first cost of the apparatus low.

The apparatus employed for this process consists mainly of an open vessel, heated either directly by the hot fire gases, or by steam. When the latter is employed as the carrier of the required heat to the apparatus, we find jackets or double bottoms and heating coils of various designs.

This process, however, is by no means restricted to operations on a medium or small scale. Of the 29,805,298 bushels of common salt, which the census of 1880 shows as being produced in the United States, a considerable portion was produced in open pans. These open pans consume about 1 pound of coal for 2.4 pounds of salt produced, which is equivalent to about 7.9 pounds of water evaporated per pound of coal.

A triple-effect evaporator at the same establishment did the work, furnishing a rather fine-grained salt with 1 pound of coal for 5.4 pounds of salt.

As an example of evaporation with hot gases, the "Porion" furnace may be mentioned here, although it is a combination between open-pan evaporation, direct hot-air evaporation and a reverboratory furnace. The furnace is employed for the recovery of soda and potash from the waste waters and refuse of beet-sugar factories, also for the same purpose in pulp-works, etc.

Theoretically the maximum effect of this furnace would be obtained when the vapor and the furnace gas combined escape to the chimney at 100° C. (212° F.), which will be about the temperature with a weak soda or potash solution. The utilization

of heat in the furnace may be calculated as follows: 1 kilogr. coal burned requires 18 cubic meters of air, which, at a 100° C., contain 561 calories. If we assume 8,000 calories produced by the combustion, there would be 8,000 — 561 = 7,439 calories available for evaporation, sufficient for 11.4 kilogr. water. The gases from the combustion of the coal amount to 23.4 cubic meters at 100° C., and the vapors to 19.38 cubic meters, total, 42.78 cubic meters, which have to be carried up by natural draft, or by mechanical means. Porion claims an evaporation of 12 kilos of water per kilo of coal; but as the combustion of the organic matter in the crude ash furnishes a certain quantity of heat, the theoretical consideration becomes rather complex. In the United States more effective apparatus is used.

Evaporation in Vacuum.

For this process closed vessels are required. They are made of various forms, but all have a space for the liquid to be evaporated, a cover or dome to collect the vapors, and, connected therewith, a surface or jet condenser, or sometimes both combined, and an air-pump to maintain the required vacuum.

The heating medium is at present mostly steam, acting in double bottoms, jackets or coils of the most varied description. The best form of arranging the heating surface is still a mooted question, and very far from being settled on anything like a fixed basis, even for operations upon a given material, as, for instance, sugar solutions. The most favorable form for the heating surface seems, however, to be an arrangement composed of tubes in different combinations and positions, and variations or counterparts of the heating surfaces employed in boilers, with such modifications as the circumstances require.

The most widely known form of this apparatus is the common vacuum pan for sugar, glue, milk, meat-extracts and colors.

The vacuum pan as made for sugar is probably the best representative of this class. The body of the pan, or "belt," is made cylindrical, or nearly so; the bottom a more or less steep cone, to facilitate the discharge of the sugar crystals; and the dome with the general outline of a cone, having on top, interposed in the pipe connecting with the condenser, a "catch-all" or safety trap,

which is nothing more or less than a separator to dissociate the entrained solid and liquid particles from the vapor before the latter is sent to the condenser.

This question of entrained liquids and solids becomes a serious one, when the value of the solutions under treatment is considerable, as is the case with sugar, soda, etc. The tension of the vapors seems to have but little effect upon the carrying capacity. Although builders of steam boilers will maintain that boilers working up to their full capacity, with a steam outlet not more than 30 inches above the mean water-line, furnish perfectly dry steam, it is, nevertheless, a fact that vapor of 1.7 pounds absolute pressure (26 inches vacuum) has sufficient carrying capacity to take up sugar and deposit the same in solid crystals 18 feet above the liquid level or boiling line. The pan, in this particular case, was excellently proportioned, so much so that every one connected with it felt absolutely sure that not a particle of sugar would ever be carried to the separator. The first boiling settled that question. But to return to the construction. The favorite arrangement of the heating surface is still that of copper pipes arranged in spiral coils. For very large pans these spirals, of which there are as many as can be placed below the boiling line, have to be subdivided into different sections, each having a separate steam inlet and outlet. Inasmuch as liquids boil under vacuum at a much lower temperature than under atmospheric pressure, we are enabled to lower also the temperature of our heating agent, such as steam, and are thus enabled to use steam of low pressure, such as exhaust steam from the steam motors, and herein we find the great economy of employing vacuum apparatus wherever exhaust steam can be utilized. The back-pressure varies in different establishments from 3 to 10 pounds. Where higher temperatures are required, direct steam from the boilers is used in some or all of the sections constituting the heating surface.

With good circulation in both the liquid to be evaporated, and in the steam in the pipes, the transmission of heat per square foot of heating surface, and 1° F. difference in temperature, will reach, in some cases, 600 British units per hour, but is more generally about 300, and may fall considerably below this.

The best record I have in my possession is from a 12-foot pan in Cuba, where we had an evaporation of very nearly 30 pounds of water per hour from the sugar liquor per square foot of heating surface, which consisted of 4-inch copper pipes. The steam pressure was 7.2 pounds and vacuum 26 inches. Unfortunately we could not measure the condensed water from the coils to obtain the coefficient of useful effect produced.

The temperature at which the liquid boils in vacuum depends, for the upper surface, upon the vacuum produced in the pan. For the bottom it depends upon the vacuum above the liquid and upon the height of the liquid above the point for which the temperature is to be ascertained. For a perfect vacuum and for a depth of water of about 31 feet, we shall again have for the lowest point a temperature of 212° before any boiling takes place. In practice, owing to the circulation of the liquids when heated, this temperature can only be approximated. As it is always desirable to maintain the greatest possible difference of temperature between the steam or other heating medium and the liquid to be evaporated, it follows that the depth of the liquor should be as small as possible, and this brings us to that construction of evaporators in which the liquids are operated upon in very thin films; in other words, to film evaporation or evaporation in transit. This process, however, is used also in some evaporators without vacuum; and since we shall have a few examples of this when we come to consider multiple-effect evaporators, it is not necessary to consider them here *ad extenso*.

From an economical standpoint, considering the utilization of the heat furnished to the apparatus, we cannot call the vacuum pan an economical apparatus, for all of the heat contained in the vapors evolved is wasted in the condensing water; but we find it, nevertheless, frequently used, especially in cases where the process has to be interrupted periodically. In such a case, other considerations than those of mere economy determine the selection of an apparatus and its mode of construction.

Evaporation by Multiple Effect.

The multiple-effect evaporating apparatus consists of a number of vessels, practically 2, 3 or 4, sometimes 5 or 6, connected with

each other in such a manner that the vapor generated in the first vessel is taken to the heating surface or chamber of the second, the vapor of the second vessel to the heating chamber of the third, and so on. The vapor generated in the last vessel is liquefied by the condenser. The first vessel only receives the heating steam either from the boiler direct, or from a receiver in which all the exhaust steam from the different engines, pumps, etc., is collected.

If n is the number of vessels employed, and if each vessel in the train performs the same amount of work, which it can be made to do when properly proportioned, and if ϵ is the total amount of evaporation, we find that the work done by each vessel is $= \frac{\epsilon}{n}$. From this it follows also that for a given amount of evaporation we require only $\frac{1}{n}$ pounds of heating steam, compared with a single-effect evaporator, such as the common vacuum pan; and at the same time, if W is the quantity of condensing water used by a single-effect evaporator, we have to supply to the condenser only $\frac{W}{n}$ pounds water for the multiple effect.

On the other hand, if we take the difference $t - t_1$ between the temperature t of the heating steam to the temperature t_1 of the last vessel, we have, for n pans, a drop in temperature of only $\frac{t - t_1}{n}$ from each vessel to the next, and we require therefore n times the heating surface which we would require for a single pan.

This means increased first cost of the apparatus, and, for this reason we frequently find to-day single-effect evaporation employed where even a double-effect would very soon pay for the difference in the first outlay.

The general arrangement of the pans, as well as that of the heating surface, varies greatly. We find vertical and horizontal pans, either cylindrical or approaching more or less to the shape of the old coffer or wagon boiler, while in the arrangment of the heating surface almost every possible form has been tried. For "evaporation in bulk" (that is to say, in those evaporations

where the entire heating surface is immersed in a body of liquor), the most favored forms are internally heated pipes for horizontal shells, and short vertical tubes heated externally for vertical shells.

The first muliple-effect evaporator appears to have been built in Louisiana by N. Rillieux and is described in United States patent, 1845.

Hugo Jelineck, of Prague, published the calculations for the "Welner-Jelineck" apparatus, in the *Zeitschrift für Zuckerindustrie in Böhmen*, and also as a separate treatise. From the latter I will give here as much as is required to show the general drift of his calculations. The apparatus is calculated for sugar liquor, but by making the special corrections for specific heats, it may be used very well for other solutions.

Let

t_0 denote the temperature of the liquor where it enters the apparatus.

t_1 — temperature at which the liquor boils.

t_2 — temperature of the heating steam.

C — Coefficient of transmission of heat per 1 square meter, 1 minute and 1° C. of the difference $(t_2 - t_1)$. This is taken at 22 French calories (kilogr. C.°) and is equal to 270 British units — lbs. F.° per hour.

F — heating surface in square meters.

Q — total calories transmitted per x square meter per minute $=$ F. C. $(t_2 - t_1)$.

l_1 — calories required to transform 1 kilogr. water from 0° C. to steam of temperature t_1 under constant pressure $= 606.5 + 0.305\ t_1$.

l_2 — latent heat given out during condensation by the steam in the heating chambers $= 607 - 0.703\ t_2$.

S — weight of steam condensed by the heating surface.

W — water evaporation by the heating surface.

From the above we have:

(1) $Q = S \times l_2$ and $S = \dfrac{Q}{l_2}$.

(2) $Q = W(l_1 - t_0)$ and $W = \dfrac{Q}{l_1 - t_0}$.

Corrections for losses to be made for special cases.

I. Single-effect Apparatus.

$t_0 = 75°$ C. $F = 100$ square meters.
$t_1 = 60°$ C. $C = 22$ calories.
$t_2 = 112°$ C. $Q = 100 \times 22 \times 52 = 114{,}430$ cal.
$t_2 - t_1 = 52°$ C.

$$S = \frac{114{,}430}{607 - 0.708 \times 112} = 216.3 \text{ kilo steam.}$$

$$W = \frac{114{,}430}{606.5 \times 0.305 \times 60} = 208 \text{ kilo water.}$$

This is equal to 124 kilo water per 1 square meter per 1 hour where the initial temperature of liquor = 750.

1 kilgr. steam evaporates 0.96 kilogr. water.

II. Double-effect Apparatus.

First Pan.

If the same drop of temperature is assumed for both pans, we have

$$t_2 - t_1 = \frac{52°}{2} = 26° \text{ C.}$$

$t_2 = 112°$ C.
$t_1 = 86°$ C.
$t_0 = 75°$ C.
$F = 100$ square meters.
$C = 22$ calories.
$Q = 100 \times 22 \times 26 = 57{,}200$ calories.
$\therefore t_1 - t_0 = (606.5 + (0.305 \times 86) - 75 = 557.73.$

$$S = \frac{57{,}200}{607 - 0.708 \times 112} = \frac{57{,}200}{527.7} = 108.3 \text{ kilogr.}$$

$$W = \frac{57{,}200}{557.73} = 102.5 \text{ kilogr. water evaporated.}$$

Second Pan.

$$t_2 - t_1 = \frac{52}{2} = 26° \text{ C.}$$

$t_2 = 86°$.
$t_1 = 60°$.
$t_0 = 86°$.
$l_2 = 607 - 0.708 \times 86 = 546.$

$$l_1 - t_0 = (606.5 + 0.305 \times 60) - 86^\circ = 538.$$

$$Q = S \times l_2 \; (S_1 = W_1) = 102.5 \times 546 = 55{,}965.$$

$$F = \frac{55{,}965}{22 \times 26} = 97.84 \text{ square meters.}$$

$S = 102.5$ kilogr. condensed steam.

$$W = \frac{55{,}965}{538.8} \text{ kilogr. water evaporated.}$$

Both pans therefore evaporate, on 197.84 square meters heating surface, 102.5 + 103.8 = 206.3 kilogr. water per minute, or 62.5 kilogr. water per square meter per hour, equivalent to 12.7 pounds water per square foot per hour.

One pound steam in this case evaporated 1.9 pounds water. The apparent reduction in the heating surface required for the second pan in this calculation is occasioned by the introduction of the high temperature of the liquor fed into the pan. Both pans should have the same heating surface.

The table on page 268 shows clearly the relation between heating surface, evaporation and consumption of steam per 100 lbs. water evaporated.

The Condenser.

The necessity for producing as high a vaccum as possible, under given conditions, has led to quite a number of different constructions for this important member of the apparatus. European designers still adhere more or less closely to the forms and proportions evolved for steam-engines, while in the United States the volume of the condenser has been considerably increased, and special attention has been paid to the distribution and division of the injection water, so as to obtain always the best result from the amount of water used.

Surface condensers are used only in cases where there is danger that particles of the solution boiling in the last pan may pass through the separator into the condenser and so be lost in the injection water, or where the condensed vapors from the last pan are intended for use, as, for instance, where the apparatus is used for producing distilled water.

Whenever possible, the condenser should be so placed that the water in the discharge pipe can form a barometric column, so

n = Number of Pans.		Single Effect.	Double Effect.		Triple Effect.			Quadruple Effect.				Quintuple Effect.				
		I.	I.	II.	I.	II.	III.	I.	II.	III.	IV.	I.	II.	III.	IV.	V.
1 $t_2—t_1$	Difference of temperature determined as $\frac{52°}{n}$ C.	52	26	26	17.3	17.3	17.3	13	13	13	13	10.4	10.4	10.4	10.4	10.4
2 t_2	Temperature of heating steam.	112	112	86	112	94.6	77.4	112	99	86	73	112	101.6	91.2	80.8	70.4
3 t_1	Temperature of boiling liquor.	60	86	60	94.6	77.4	60	99	86	73	60	101.6	91.2	80.8	70.4	60
4	Pressure on vacuum gauge, mm.	608	304	608	112	442	608	27	300	434	608		207	393	521	608
5	Absolute pressure in mm.	152	456	152	648	318	152	733	460	266	152	804 (+44)	553	367	239	152
6 S_{m_2}	Amount of heating steam condensed per sq. meter per hour, in kilogr.	129.7	64.98	61.5	43.35	40.81	41.16	32.52	30.54	30.73	30.92	26.01	24.40	24.51	24.60	24.73
7 W'_{m_2}	Amount of water evaporated per sq. meter per hour, in kilogr.	124.8	61.5	62.28	40.81	41.16	41.52	30.54	30.73	30.92	31.11	24.40	24.51	24.60	24.73	24.74
8 C	Coefficient for transmission of heat. Calories 1° C. kilogr. per sq. meter per minute.	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
9 F_a	Theoretical heating surface for 100 sq. meters in first pan, with temperature of liquor 75° C.	100	100	97.84	100	96.2	99	100	95.5	98	100	100	95.1	96.8	98.7	100.3
10	Pounds or kilogr. of water evaporated by 1 lb. or kilogr. of steam furnished to the first pan. Total	0.9	1.96		2.85			3.79				4.72				
11	Steam required to evaporate 100 kilogr. water in kilogr. or 100 lbs. water in lbs.	111.11	51.03		35.08			26.38				21.18				

that the condensing water may flow away to the hot-well without passing through the air-pumps. The bottom of the condenser should, therefore, be placed rather more than thirty feet above the discharge opening of the "barometric pipe," so as to obtain sufficient head to produce the required velocity besides the height required to form a seal against the atmosphere.

With this position of the condenser the air-pump has only to discharge the air from the apparatus, together with some vapor and any gases liberated during the process. A small amount of water is admitted into the cylinder to fill the clearance at each end. The air-pump in this case can be comparatively small, and the danger of flooding the condenser, and thereby ruining the contents of the pan in case of a sudden stoppage of the air-pumps, is thus avoided. The objection to this position of the condenser is that it necessitates the pumping of the condensing water to an elevated tank, from which it can be drawn into the condenser. A very simple calculation will, however, in each case decide whether it is cheaper to pump the condensing water to the required height, or to remove it against any vacuum desired to be carried in the condenser by the air-pump.

Where the entire apparatus must be kept low, and where an elevated condenser with a barometric pipe is therefore inadmissible, the injection water, together with the air and gases and the condensed water from the vapors resulting from evaporation, must be removed by the air-pump. The condenser is then placed at such a height that the pump has a sufficient column of water to insure proper action of the suction valves and a direct flow of air into the air-pump cylinder as soon as the condenser is drained.

In order to obtain a good result from the condensing water, it is necessary that it be subdivided into as fine particles as possible as soon as it enters the condenser, and distributed evenly through the entire space in the condenser shell.

The principal arrangement of a condenser much used at present is shown in Fig. 2. The injection water enters through inlet pipe i, and is broken up into fine streams by the upper perforated plate s, from which it falls, passing the vapor inlet $V\,I$ from the evaporator, onto the lower perforated plates s_1, s_2, s_3 and s_4.

These lower plates, s_1 and s_4, reach only a little more than half way across the condenser, so that the vapor is forced to follow a zig-zag course through the dense rain filling the entire inner space of the condenser. At the bottom of the condensing space we often find a funnel-shaped guard *b b*, to prevent larger quantities of water being drawn into the pump and also to form a space for the accumulation of air, whence it is drawn continually by the air-pump through nozzle *a*. Quite an appreciable amount of air, however, is carried down the discharge pipe *D* if a sufficient length of barometric pipe is used. This can readily be ascertained by observing the hot-well overflow.

The principle here indicated is applied in many variations, the object being always to obtain an even distribution of the injection water, no matter how much the injection valve may be closed.

In order to admit of ready cleaning in case the perforations in the distributing plates become stopped up with impurities from the water, they are sometimes made reversible from the outside by being mounted on transverse shafts passing through stuffing boxes in the shell.

In place of the upper distributing plate we often find perforated pipes entering from the side, or we find the water projected from an upturned nozzle against the under side of the cover, which is then covered with a number of ribs, arranged in a suitable manner, all pointing downward and having the lower edge serrated so as to form points for the water to drop from.

The Air-Pump.

According to the position of the condenser, the air-pump becomes either "dry" or "wet," as was indicated in describing the condenser. Quite a large variety of designs have been adopted from time to time in different localities and by different makers of vacuum apparatus. The most favored construction to-day in the United States is the combination of air-pump and steam cylinder, very much in the same manner as in the well-known direct-acting steam-pump. On account of the elastic resistance of the air-piston, however, the pistons should always be coupled to a fly-wheel and crank-shaft.

These pumps are readily obtained from reliable builders, and it is therefore not necessary to enter into any detailed description of their construction and action.

The selection of the size of cylinders required, and of the construction most suitable for each special case, must be governed rather by experience than by theoretical calculations, as will be seen by the following:

The air drawn into the apparatus may be divided into four distinct classes, viz:

(1) Air drawn in with the solution to be evaporated.
(2) Air drawn in with the injection water.
(3) The gases evolved from solutions during evaporation.
(4) Air drawn into the apparatus through leaks in the outer shell.

We can form an estimate of the amount of air coming in with the solution from the amount of air which water can dissolve at different temperatures, for which Bunsen gives the following proportions:

At 32°	F.	water	dissolves	0.02471	volumes	of	air.
" 41°	"	"	"	0.02179	"	"	"
" 50°	"	"	"	0.01953	"	"	"
" 59°	"	"	"	0.01795	"	"	"
" 68°	"	"	"	0.01704	"	"	"

This table also gives some clue to the amount of air liberated from the injection water, but the volume of gases evolved by evaporation, and the quantity of air entering through leaks, are entirely unknown factors.

The amount of piston displacement given to the air-pump by European designers per pound of steam to be condensed, is very much larger than that given by the usual practice in the United States, where the piston displacement varies from $\frac{3}{4}$ cubic foot to 2.5 cubic feet for each pound of steam to be condensed, while the European apparatus imported into this country often shows as high as $3\frac{1}{2}$ cubic feet per pound of steam to be condensed.

Wet air-pumps have from two to five times the volume of the injection water, and should have more if possible. European journals recommend 15 volumes of injection water as the proper piston displacement.

The water condensed in the heating chambers of the different pans has the temperature of the steam prevailing in that space, since very little heat will be extracted by the bottom parts of the heating surface, when the steam is on the inside of the tubes or drums. Where the steam is outside the tubes, the condensed water will all go to the lowest part of the shell, and it will then be at the temperature of the steam from which it was condensed. All of this water of condensation should therefore be carried along parallel with the vapors from each effect, but not necessarily through all the heating chambers. Practically it may be sent directly, through interposed traps properly constructed, to the last heating chamber. Since this last chamber is under a partial vacuum, it is necessary to remove the water of condensation by a pump.

A numerical example will make this clearer. If we take a triple-effect of 7,200 square feet heating surface, or 2,400 square feet in each pan, we will have, at an evaporation of 5 pounds water per hour per square foot, 12,000 pounds steam per hour, condensed on the heating surface of the next succeeding pan, or 200 pounds condensed water per minute in each pan. Assuming a difference of temperature for any two pans of 36° F., we have from the first to the third pan, 72° F.; therefore in the 200 pounds about 14,400 units of heat, and for the 36° from the second to the third pan 7,200 units, making a total of 21,600 units abstracted from the heat available for the third pan. In round numbers this pan will therefore evaporate per minute about 21 pounds water less than it would if it had the benefit of the condensing water.

Frequently, however, the conditions prevailing in a manufacturing establishment are such that a large quantity of pure hot water is very desirable, either as a solvent or as final wash-water. These waters being distilled, can very often not be replaced by heated water from wells or rivers, and in such a case it becomes a matter for serious consideration whether the condensed water should be carried along in the evaporator, or whether a small loss in evaporation is not largely overbalanced in other departments of the factory by the convenience of having this quantity of hot distilled water always at disposal. At the same time, the condensed water, when so used, forms a very desirable check on

the apparatus, for the reason that when this water is not pure it is known that something is wrong with the apparatus. It is either of faulty construction, or it is out of repair. In either case it should be looked after.

This question of relative economy, when the running of a complete factory is considered, brings us to the much-discussed question of engines. The discussion going on in the European journals throws but little light upon the question, since the comparison is there based mostly upon engines consuming up to 90 pounds of water per hour, and 33 per cent. cylinder condensation. Since such engines are hardly tolerated here, it is unnecessary to go into any details on that score. There is, however, another side to this question, which I will point out, but leave the discussion for another evening. In every factory using evaporators of either single or multiple effect, heated with the exhaust steam from the engines, pumps, etc., there will be times when the evaporators are shut down and the exhaust is not used. At such times it is desirable to take off all back pressure and to have the most economical engines obtainable. But another solution presents itself, when we take into consideration that very often with the stoppage of the work, for the evaporators, pans, etc., the demand for power also diminishes, and it becomes a question for the constructing engineer whether the factory, as a whole, will not run more economical with a number of small and reasonably economical engines requiring little care and attention, than by employing one large central engine of a very high class. The tendency is naturally toward central high-class engines using the minimum of water and fuel. But, unfortunately, factories requiring large amounts of evaporation are often spread over large areas requiring all kinds of devices for cheap transmission of power to the places where it is used, and worse than this, the demand on the power-plant is subject to very great variations. The large central engine is then badly handicaped. I recall an instance where a total of 1,000 horse-power was used under 8 pounds back-pressure in one department, and, although the factory runs continuously, the demand for power sometimes went for hours as low as 60 horse-power. In such a case, the free exhaust of 1,000 horse-power for one hour will go a very long way to make up the difference in economy of smaller and somewhat less

perfect engines. Moreover, as long as all the exhaust steam is utilized, the consumption of steam does not greatly vary in the good engines now in the market, since the engine then uses only the steam due to the condensation in the engine and to the work performed.

But this entire discussion belongs more properly to the subject of "central" versus "divided" power, which, in connection with the profitable use of exhaust steam, must, in every case, be decided on its merits by the engineer in charge.

In order to obtain continuously a high rate of efficiency from the heating surface, it is necessary that the accumulated air and other gases be continuously removed from the heating chambers or coils. This can be accomplished by properly constructed traps, when separate coils with end outlets to each section are used, as in single-effect vacuum pans. Stating the problem more generally, it is only necessary to connect the "dead space" of the heating chamber with a properly constructed outlet. Practically this is not always easily done. Either the dead space is not so easily determined, or there are a large number of spaces, and in that case the air must be removed from each one separately. The importance of this continuous removal of accumulated air appears to be frequently underestimated, but it must be remembered that not only that part of the heating surface where the air is accumulated becomes absolutely valueless, but also that the transmission of heat from a mixture of air and steam is considerably less than that from pure steam alone, and that thereby the efficiency of the entire surface is considerably reduced.

When the solutions under treatment evolve considerable quantities of gases, such as ammonia from beet-root juice, it becomes necessary to provide special appliances for their removal; but where only air is present, and especially in pans with large heating chambers, such as are used in the Robert system, it will be found sufficient and very effective to connect the top and the bottom of the central part of the chamber by a small pipe, either with the vapor space of the same pan or with the heating surface of the next, and to provide only a common globe valve to regulate the amount of steam and air "blown through." With this arrangement there will be a small loss produced by blowing

some small amount of steam direct from the heating chamber of the last pan to the condenser. This steam, however, is vapor from the preceding pan, and the loss is experienced only in the last pan. In practice it is found to be far more advantageous to submit to this small loss than to reduce the efficiency in all the pans. Since the data for any numerical calculations in this direction can be found in any of the better hand-books on heat, and since the calculations themselves are very simple, I will not take up your time with them to-night.

Formulas and theories which are reprinted from European publications are to be taken cautiously, as will be seen by the following. In a reprint of a "Treatise on Sugar-making," by Mr. P. Horsin Déon, I found the following assertions:

Let x denote the quantity of heat given off by the surface in a given time τ, then

$$x = \tau \frac{k}{e} (V - t)\, s, \text{ in which}$$

k = coefficient of the conducting power of the metal.
e = thickness of the metal.
s = the heating surface.

Supposing $\tau = 1$ second,

$s = 1$ square meter,

$V - t = 1°$, we have $x = \frac{k}{e}$.

These tubes are made of brass, 1mm. thick, the coefficient of conducting power of which is $k = 69$; that is to say, the quantity of heat given off by a plate 1 meter thick, the two planes of which are at a constant temperature, is 69 calories per hour, with a difference of 1° temperature. Thus the thickness of 0.001m. or 1mm. gives $x = 69{,}000$ calories, which gives, for the quantity of vapor or steam condensed on that surface, $\frac{69{,}000}{650} = 106$ kilgr.; but this theoretical coefficient is admissible only in cases where the juice which covers the two surfaces is renewed as quickly as possible, and this is not the case in practice. It varies greatly, according to the construction of the vessel, as it is not the same in a steam chamber with a double bottom or tubes.

Transposing this into Fahrenheit degrees and pounds, would give:

106 kilgr. steam condensed per hour on 1 square meter, or 10.76 square feet = 233.2 pounds per 10.76 square feet, or about 23 pounds water condensed per square foot for 1° Celsius, or 12.8 pounds water per square foot and 1° Fahrenheit. If we assume a difference in temperature of 100° F. between the two sides of the heating tube, we should have 1,280 pounds of water (condensed steam) from 1 square foot.

No one who is at all acquainted with the high standing of Mr. Horsin Déon, will for a moment assume that such a statement emanated from him. We shall have to look to the translator for an explanation.

The most convenient form of steam diagram for the volumes, temperatures and pressures relating to multiple effects, is obtained by arranging the two curves in the manner shown in the diagram herewith. Then, if n be the number of pans employed, we have only to divide into $1 + n$ equal parts the distance between the temperature of the heating steam drawn from the steam recipient of all the exhaust steam available, and the end-temperature, *i. e.*, that of the vapor discharged by the last pan to the condenser, and draw the ordinates to the curve of pressures and temperatures. The horizontal divisions furnish them the required data for pressures and volumes direct. It is assumed in this case that the pans connected in one apparatus are all alike, and that all are doing an equal share of the work. If any changes from this are proposed, the results to be obtained by such changes can easily be taken from the diagram.

The conditions to be fulfilled by a good evaporating apparatus may be summed up as follows:

(1) There shall be no very heavy pieces difficult of transportation.

(2) The entire apparatus shall be comparatively small.

(3) The heating surface of the apparatus shall be large, as compared with its size.

(4) The heating surface shall be so arranged that all surfaces in contact with steam shall act as heating surface.

(5) The heating surface must be readily accessible for cleaning and repair. Cleaning comprises the removal of deposit from the solutions under treatment, as well as the re-

moval of grease, etc., deposited on the steam side from the steam or vapor.

(6) The heating surface shall admit of being readily increased without deranging the shell or other parts of the evaporator.

(7) There must be a good circulation in the liquid to be boiled and in the heating steam or vapor.

(8) The solution to be boiled shall be shallow.

(9) Air and condensed water shall be readily and continuously removed from the heating chambers.

(10) The catch-all shall be effective in removing entrained particles of solution and preventing the boiling over of solutions, and shall not cool the vapors by radiation.

(11) All "pumping back" of solutions during evaporation must be avoided.

(12) All vapor and steam connections from one pan to another shall be as large as practicable, so as to obtain low velocities of vapor in these connections.

In an apparatus designed by Mr. G. M. Newhall and the writer, and which is built at present by the G. M. Newhall Engineering Co., Ld., it was sought to embody all the requirements enumerated above. The outside form selected for the shell resembles that of the old Watt wagon boiler, as this was also adopted by a number of European designers. In place of the small tubes employed in the Jelineck apparatus, we have adopted a heating surface based on the same principles as that of a water-tube boiler.

The shell is made in the shape of a rectangular box, of cast-iron plates, bolted together with a semicircular top or dome. The heating surface consists of a combination of inclined pipes—an inner one, open at both ends, to produce a definite circulation of the liquid, and an outer one, extending from the inner plate of the steam-box on one end to the corresponding plate of the steam-box on the other end. In Plates I and II these steam-boxes are made sectional, constructed as headers, all bolted at one end to a corresponding steam-inlet in the side of the shell, while the other end is merely supported, so as to admit of unequal expansion and contraction. The outside pipes, therefore, represent the usual heating surface of an internally heated pipe in the well-known horizontal pans, while the inner pipes give all the ad-

vantages of external heating with rapid internal circulation. The large body of this circulating liquid must at the same time give a similar return current around the outside pipes, and thereby prevent the presence of any stagnant liquor in the pan.

This violent circulation rendered it necessary to make special provision for retaining the entrained liquor. For this purpose the entire upper part of the dome is utilized. We do not rely upon a large vapor space, which is proved by experience to be of doubtful utility, but use in place thereof a number of baffle-plates, so as to throw the steam into a zig-zag course. The bottom of the channel in which the vapor moves is formed by a perforated plate, with a channel below, so that all liquor separated from the vapor is returned at once to the boiling liquid at the lower end of the pan.

The heating tubes are secured in the headers by stuffing boxes with intermediate glands, so that the loosening of four bolts will loosen the pipes on both ends and admit of their complete removal from the pans. If a sufficient supply of spare pipes is kept on hand, a number of those in the pan may be taken out and replaced by clean ones, and those removed may then be cleaned at leisure. Or, when a full set is at hand, a new set of tubes can be inserted in a short time, and the boiling continued while the tubes are being cleaned.

As is shown in Plates I and II, all the pipes in one header form one section of the heating surface, independently of the other rows of tubes. We are thereby enabled to use in a pan as much heating surface as is convenient, or we may erect an apparatus with only one-half or even a third of the ultimate total surface, and add thereto as the growth of the factory may require.

The inclination of the pipes allows the condensed water to travel in the same direction as the steam in the annular space between the inner and the outer tube toward the lower headers. These are connected vertically at each end by an opening. A narrow "facing strip" around the opening allows the joint to be made by a single strong bolt passing vertically through all the headers collectively. The facing is made flat, so as not to interfere with unequal expansion. The accumulated air and the condensed water are taken off from the chamber thus formed by these lower communicating headers, as described above.

Every part of the heating surface, therefore, which is in contact with steam, is also in contact with liquor under treatment, the outer shell simply serving as a receptacle to retain the liquid. Its form being simple, it can as easily be lagged or otherwise protected from radiation as a steam-pipe. All joints are easily made, and the shell may be made up of as many pieces as desired. These may be even sufficiently small to admit of transportation by pack-mules.

The form of condenser shown is one for a "wet pump," when placed directly on the staging; but it will easily be seen that very slight alterations will make it suitable for either system. It is immaterial also what construction is adopted for the condenser.

Another arrangement of a triple effect, designed by Mr. H. G. Morris, on strictly scientific principles, is shown in the annexed illustrated *circular*.* The figure shows inclined heating tubes in the lower drum, large connections which insure good circulation of the liquid into and from the upper drum, large vapor space and good provision to prevent entrained liquor being taken over into the next pan. The simple form of the exterior admits of proper protection against radiation. (Since Mr. Morris is present, it will not be necessary for me to enter into details now.)

The *blue-prints*,* kindly loaned by Mr. Beaumont, of the firm of Joseph Oat & Son, of this city, show the outside elevation and plan of a vertical and horizontal triple effect, which are excellent examples of the apparatus used to-day in sugar plantations.

Of the three *blue-prints** courteously sent me by Mr. R. Deeley, of New York, for to-night, one shows a modern combination of a vacuum pan (single effect) with a triple-effect evaporator, one a double-effect evaporator, and one an independent pan, as they are built for sugar plantations, etc. The drawings are complete in themselves, so that very little need be said about the apparatus shown. I will only add that the heating surface for the vacuum pans consists of copper coils, the inlets of which are shown, arranged so as to use either high or low pressure steam; while that of the double and triple-effect evaporators consists of vertical tubes, as in the Robert system, with large central "down-

* The blue-prints and circular referred to have been presented to the Club by Mr. Müller and may be seen in the library.

take" to insure proper circulation. Like the drawings already noticed, they represent modern practice evolved by long experience.

All the apparatus shown belongs to the class which treats the solution or liquor "in bulk," *i. e.*, a quantity of liquor contained in one pan remains in contact with the heating surface until the required density has been obtained, during which time it is in more or less rapid circulation, but at all times there is a sufficient quantity present to keep all the heating surface entirely submerged in a body of liquid.

The next class is that wherein the evaporation is performed "in transit" or by "film evaporation," as it is called. In these evaporations the liquid under treatment passes in thin films or streams over or through heated pipes, frequently covering only a part of the heating surface. The representative apparatus of this class is the Yaryan system, but unfortunately I have not been able to obtain any *blue-prints* or other data, except those contained in their excellent trade catalogue.

Based on the same principle of externally heated pipes through which the liquor passes, is the Lilly evaporator, for a description of which I have to refer anyone interested to the extensive specification published by the Patent Office. Internally heated pipes, over which the liquor passes in a thin film, much in the same manner as in the early apparatus of Mr. Derosne, and later that of Hanslin and Gutsche, of Breslau, are used in the apparatus designed by Mr. Thos. Gaunt, but unfortunately I can only give an advertisement illustration of this interesting apparatus.

It would exceed the limited time of one evening to attempt even a short description of the different evaporators built in the United States alone; among the more prominent ones are the names of the "Swenson," built by the Fort Scott Foundry; The Pioneer Iron Works, New York; West Point Foundry on the Hudson; The Yaryan Evaporator; R. Deeley & Co., of New York; and Joseph Oat & Sons, of this city.

A few remarks relating to the history and development of multiple evaporation may not be out of place here. The first apparatus definitely using the same heat in successive distillations and evaporations, appears to have been constructed by

Pequeur, in France, about 1829, and some limited use seems to have been made of apparatus built on his principle, without, however, being introduced to any marked extent.

The credit of being the first constructor of a thorough practical apparatus employing the repeated use of the same heat, belongs to Mr. Nobert Rillieux, a native of Louisiana, who developed the invention in the United States as early as 1842. Mr. John Dymond, editor of the "*Louisiana Planter*," kindly sent me a number of data relating to the early history of the apparatus, and I quote from his letter: "In Mr. McCullough's report to the Secretary of the United States on Sugar and Hydrometers, Senate Document, Thirtieth Congress, First Session, Executive Document, No. 50, page 248, Mr. McCullough speaks of the Derosne apparatus, which was then in use in Cuba, where he saw it. On page 251, Mr. McCullough speaks of the Rillieux system, and remarks that in it the use of the latent heat of the vapor from one portion of the syrup for the evaporation of another portion has been accomplished far more perfectly by Mr. Rillieux than by the system of Derosne. The apparatus was erected by Messrs. Merrick and Towne, of Philadelphia. . . . I have since learned definitely that the Myrtle Grove apparatus was erected by Mr. Rillieux, in 1842. (The plantation, 'Myrtle Grove,' belonged to Mr. T. J. Packwood, and is situated in the parish of Plaquemines.) He tried an apparatus in 1841 and failed, and then went to Paris, returned in 1842 and made his apparatus a success. In 1843 he erected three apparatuses. . . . All this comes from a gentleman who knew him personally. Mr. Rillieux is now living in Paris, and has been continuing to perfect his evaporating devices by increasing the economic use of latent heat. Mr. Horsin Déon, the well-known French sugar chemist and engineer, is there the promotor of the use of the Rillieux apparatus, and has successfully introduced it into Russia and Austria. Mr. Rillieux is a very learned man, and when the late Hon. Duncan F. Kenner, one of the best planters of our State, looked him up in Paris some ten years ago, he found him in one of the libraries, studying Egyptian hieroglyphics. The old gentleman is now living in Paris, probably over 80 years old, and has some relatives living in this State."

Whether Tischbein and others obtained the drawings and sketches surreptitiously or not, is hardly within the scope of a short paper. The fact remains that the invention spread rapidly over the sugar districts in Europe, where the apparatus, with vertical tubes in the heating chamber, which is still so popular, was constructed by Robert, in Seelowitz, in Austria. From that time on a large number of different designs have been patented and tried, some have come into extensive use, while others—the larger number—are quietly resting in the pigeon-holes of the patent offices of the United States, England, Germany and France. Notwithstanding all these efforts, the latest evaporators built by Mr. Rillieux for beet-juice evaporation are not excelled by any in completeness of design or in economy, but none of them have been sent to the United States during the last few years, as far as I have been able to learn.

Annexed are copies of *two circulars* kindly sent me by Mr. H. G. Morris, which will show to what perfection Mr. Rillieux had brought his apparatus in 1847 and 1848, and they certainly now form important historical documents relating to the early history of multiple-effect evaporation.

Circular No. 1.

(Translation.)

Mr. N. Rillieux, *New Orleans, February* 15, 1847.
New Orleans.

Dear Sir:—For the purpose of ascertaining the comparative results of making sugar by the old process with kettles, and by the apparatus of N. Rillieux, I have made the following experiments:

First I converted the juice from 25 arpents of cane, by the old process, with my ordinary set of kettles. I obtained 26 hhds. of sugar, weighing about twenty-seven thousand pounds (27,000 lbs.) and seventy-three (73) gallons of molasses per hhd.

Eight days afterwards I took the juice from twenty-five (25) other arpents (of the same field as before, and of cane in precisely the same condition) and converted it into sugar by N. Rillieux's apparatus. I obtained thirty-one and three-quarter hhds. ($31\frac{3}{4}$) of first sugar weighing net 34,121 pounds and 53 gallons of molasses per hhd.

These comparative trials were made at my upper plantation at English Turn.

A few days afterwards I made further experiments at my lower plantation at Poverty Point, for the purpose of ascertaining what quantity of sugar could be obtained from the molasses made by the Rillieux apparatus.

The results are as follows:

When I arrived at the plantation I found 68 hhds. of sugar made by the N. Ril-

lieux apparatus. I reboiled the molasses therefrom, and obtained 22 hhds. of sugar, which, after draining one month, diminished to 17 hhds. of 1,000 lbs. each, making 17,000 lbs. of sugar. I also obtained 20 gallons of molasses per hogshead of this sugar.

I sent the sugar made by the two processes to New York, and they were sold upon the same day. That made by the old process sold for six and three quarter cents per pound. That made by Rillieux's process sold for eight and a quarter to eight and a half cents per pound. The sale took place on the 20th of January, 1847, on which day the prices were low in New York.

When shipped from my plantation, the hoghsheads of N. Rillieux's sugar were heavier than the hogsheads of common sugar. The loss of weight during the voyage from here to New York was 60 lbs. per hhd. of apparatus sugar.

(Signed) A. Lesseps.

N. B.—Mr. Lesseps informed Mr. Towne (late Merrick & Towne) that the greatest part of the apparatus sugar sold for eight and a half cents.

Merrick & Sons,
Southwark Foundry,
Philadelphia.

Circular No. 2.

New Orleans, February 1, 1848.

Sir:—As the subject of the inclosed is of such great interest to our State, I do not deem it necessary to offer any apology in presenting it to you for consideration.

I applied to Mr. Rillieux, as the person best qualified by his known talents as an engineer, and experience in sugar making, for information on the subject; and I feel assured that his letter and tables will be found well worthy the careful attention of our enterprising planters. I have other communications on this subject; but as his letter and tables are so full and complete, I think it only necessary to refer to the comments of Mr. W. Elihu Thompson, Engineer, who took off the last two crops of Messrs. Armand & Brothers with a 24,000 lbs. N. Rillieux four-pan apparatus. He says that they have run it at the rate of 32,000 lbs. in twenty-four hours with perfect ease; and that on a trial made in presence of Mr. Valcour Aime's engineer and others, and on the 5th of January last, they proved by actual measurement that the consumption of wood was but one-half cord per 1,000 lbs. sugar. Mr. C. G. Allen, the engineer who took off the last two crops of Mr. Camille Zeringue with a 9,000 lbs. N. Rillieux three-pan apparatus, says that they made 21,000 lbs. first sugars, and 3,500 lbs. second sugars in forty-eight hours. Mr. Lessep's 12,000 lbs. N. Rillieux three-pan apparatus has made 16,000 lbs. first sugars and 6,000 lbs. molasses sugars in twenty-four hours. And similar results have been produced with other of these apparatus.

Professor McCullough was appointed by Act of Congress, 3d of March, 1843, to investigate the different methods of sugar making in the West India Islands and in this State. In his report to Congress, 1st of March, 1847, he remarks on the process of N. Rillieux: "The use of the latent heat of the vapor from our portion of syrup, for the evaporation of another portion, has been accomplished far more perfectly and fully by an apparatus invented by N. Rillieux, of New Orleans, than by the system of Mr. Derosne. This apparatus has also the merit of being simple, and therefore the more easily constructed or repaired; so that it is less expensive and less liable to derangement. It may now be considered as fully tested, and as perfectly successful;

so that it may be adopted with entire security and certainty of results." He also adds: "When in Louisiana, I visited the plantation of Messrs. Benjamin & Packwood, at their invitation, and carefully examined the apparatus of N. Rillieux, constructed for them by Messrs. Merrick & Towne. From what I learn from these intelligent gentlemen, as well as what I saw there, I can bear witness to the entire success of the system." He adds also: "Liquoring may be performed in pneumatic pans or tigers, but there is some difficulty experienced in the operation in consequence of obstruction if it be urged very rapidly. When I was in Louisiana, Messrs. Benjamin & Packwood had tried unsuccessfully to overcome the above-mentioned difficulty of obstruction; they have since succeeded entirely, and their present crop has been manufactured, with Rillieux's apparatus and pneumatic pans, into liquored sugar of perfect quality. A specimen of this sugar, presented to me by Messrs. Merrick & Towne, has been analyzed by me, and found to be chemically pure. Its crystalline grain and snowy whiteness are also equal to those of the best double-refined sugars of our Northern refineries. To Messrs. Benjamin & Packwood must therefore be awarded the merit of having first made, directly from a vegetable juice, sugar of absolute chemical purity, combined with perfection of crystal and color. This is indeed a proud triumph in the progress of the sugar industry. In the whole range of the chemical arts I am not aware of another instance in which a perfect result is in like manner obtained immediately."

If there is any error in the statement of the results of the apparatus, or either of the methods, I shall be most happy to be informed of it by the planter, and to have it corrected. As the Factor for several of the planters having the N. Rillieux apparatus, I am enabled to verify the statement of Mr. Rillieux, as to the prices of the sugars, and quantity.

The terms for the apparatus are so easy that the most cautious planter need not hesitate in getting it. It is important that early application be made by those who want it for the next crops, to insure the execution of their order in time.

With great respect,

Your most obedient servant,

W. E. Thompson,
Agent for Merrick & Towne,
Philadelphia, Penna.

The distillation of water for ice factories is to-day practiced in a very limited way—by only two or three ice manufacturing systems—for the simple reason that the ice manufacturer depends very largely on the builder of the machine for instructions as to the manner in which to run and arrange his machinery. The present practice is to condense the exhaust steam from the engine, after it has passed through an oil separator, which extracts the lubricating materials used in the cylinder, then to boil the water in order to extract all the air, and then to pass it through a system of filters and coolers until it reaches the freezing cans. This is the distilled water of the ice factories, very

pure and tasteless when the engineer is careful, but just as bad and repulsive where the engineer is not always on the lookout. However, we will assume that the first is always the case, and the water and ice above reproach, as it is in reality in most cases. A good Corliss engine, such as our manufacturers now furnish, will never furnish sufficient exhaust steam to produce the amount of water required for the ice, and the usual resort is to provide extra boiler power to supply the deficiency of steam.

While it is not disadvantageous for the manufacturer to have an extra boiler on hand in case of necessity, there certainly is no excuse for wasting under that boiler every day an extra ton or two of coal which should not be used, since more than the required amount of water can be had by a good small double-effect evaporator, constructed to combine the properties of a distilling and evaporating apparatus, and combined with a heat exchanger so as to save the waste heat from the condensed water of the first pan or vessel. This does away with all the oil extractors, filters and their adjuncts for cleaning them and keeping them clean. As far as installation is concerned, the cost of the two systems will be about even, while the saving of coal will very soon leave a considerable credit for the evaporator. When it is once thoroughly understood that by using multiple-effect evaporators, 40 pounds of sea-water are evaporated by 1 pound of coal, and that even 50 pounds are to-day within the range of the possible, without running into excessive cost, our ice manufacturers and others using pure distilled water will hardly be satisfied with an evaporation of from 8 to 10 pounds per pound of coal, especially since they can, by properly utilizing the heat contained in the exhaust steam of the compressor engine, readily obtain a full supply of pure distilled water, in place of a partial supply of condensed steam which requires purification. Where the proportion of steam taken direct from the boiler for condensation is comparatively large, as it is in some of the absorption machines, it becomes all the more important to resort to multiple-effect evaporation.

It is a curious fact that in ice manufacturing, where the entire process is based upon the economical handling of a large amount of heat, this important part of the process has been overlooked,

and considerable losses are permitted which would not be tolerated for a moment in the engine or on the ammonia side of the apparatus.

The literature on this subject is widely scattered through a large number of periodicals and mainly through the hand-books on sugar manufacturing.

As a partial list I will append the following:

Walkhoff, Stammer, Stohmann and Horsin Déon on Sugar Manufacturing.

Peclet's Treatise on Heat.

Forster and Sach on Evaporation.

Among the journals which contain valuable contributions on this subject are:

The Louisiana Planter.

Dingler's *Polytechnic Journal.*

Most of the European journals on the manufacture of sugar.

Uhland's "Constructeur" and Wagner's Annual Reports; and last, but not least, the Patent Office Reports of the United States, England, Germany and France.

Coefficients for transforming French calories to British units of heat, etc.:

1 French calorie = 1 kilogram water raised 1° Celsius at maximum density.

1 unit of heat = 1 pound water raised 1° Fahrenheit at maximum density.

1 calorie = 3.968 units heat.

1 calorie per 1 square meter = 0 3687 units per 1 square meter.

1 calorie per 1 square meter per 1° Celsius = 0.204 units per 1 square foot per 1° Fahrenheit.

1 square meter = 10.76 square feet.

1 degree Celsius = 1.8° degree Fahrenheit.

1 atmosphere = 760 millimeter mercury column and 29.92 inches mercury column.

1 (lb.) pound pressure = 2.037 inches mercury column.

Plate 1

Newhall – Müller
Evaporator.
Vertical Section.

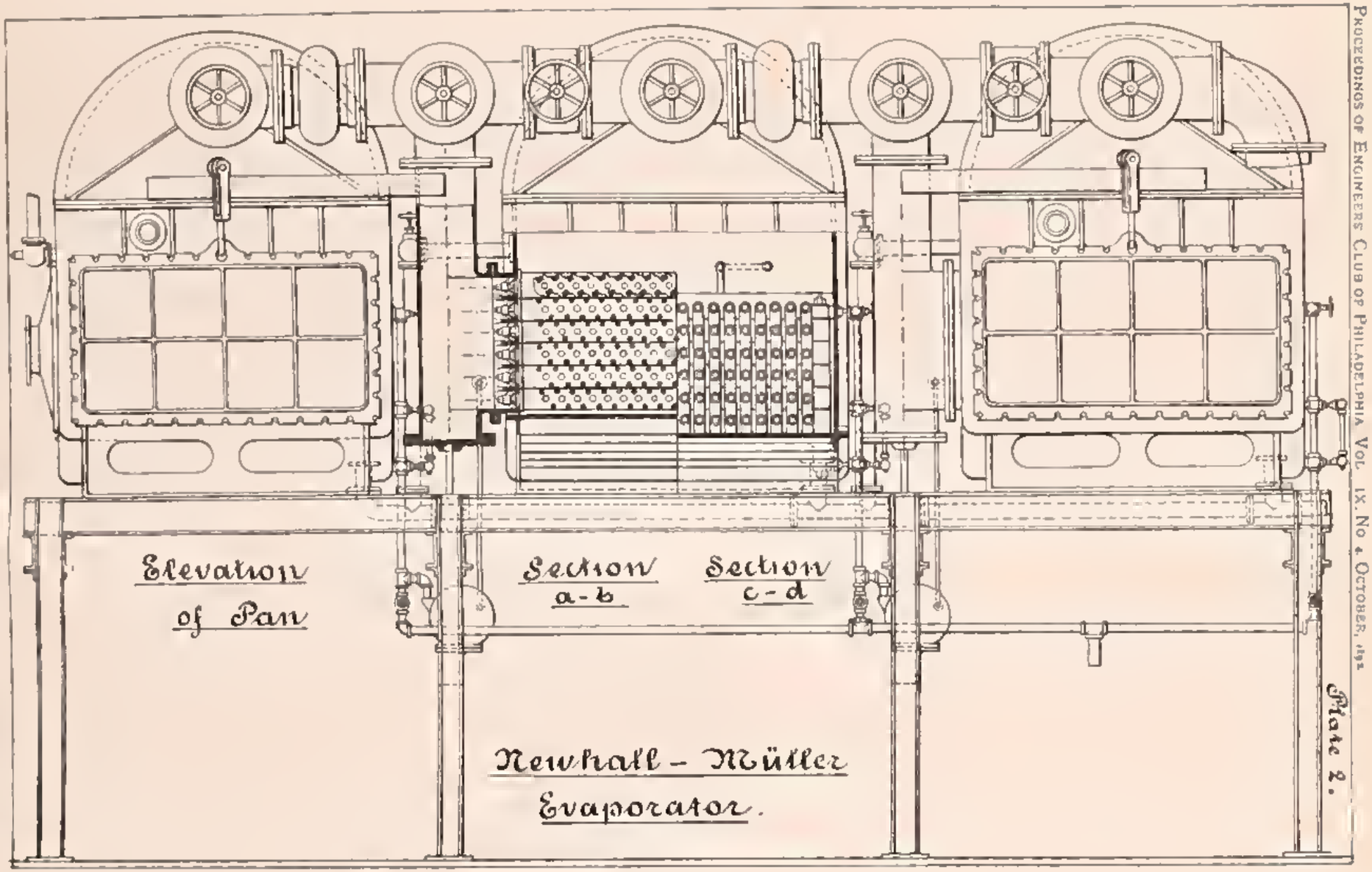

Elevation of Pan
Section a-b
Section c-d
Newhall - Müller Evaporator.

Plate 2.

Plate 3

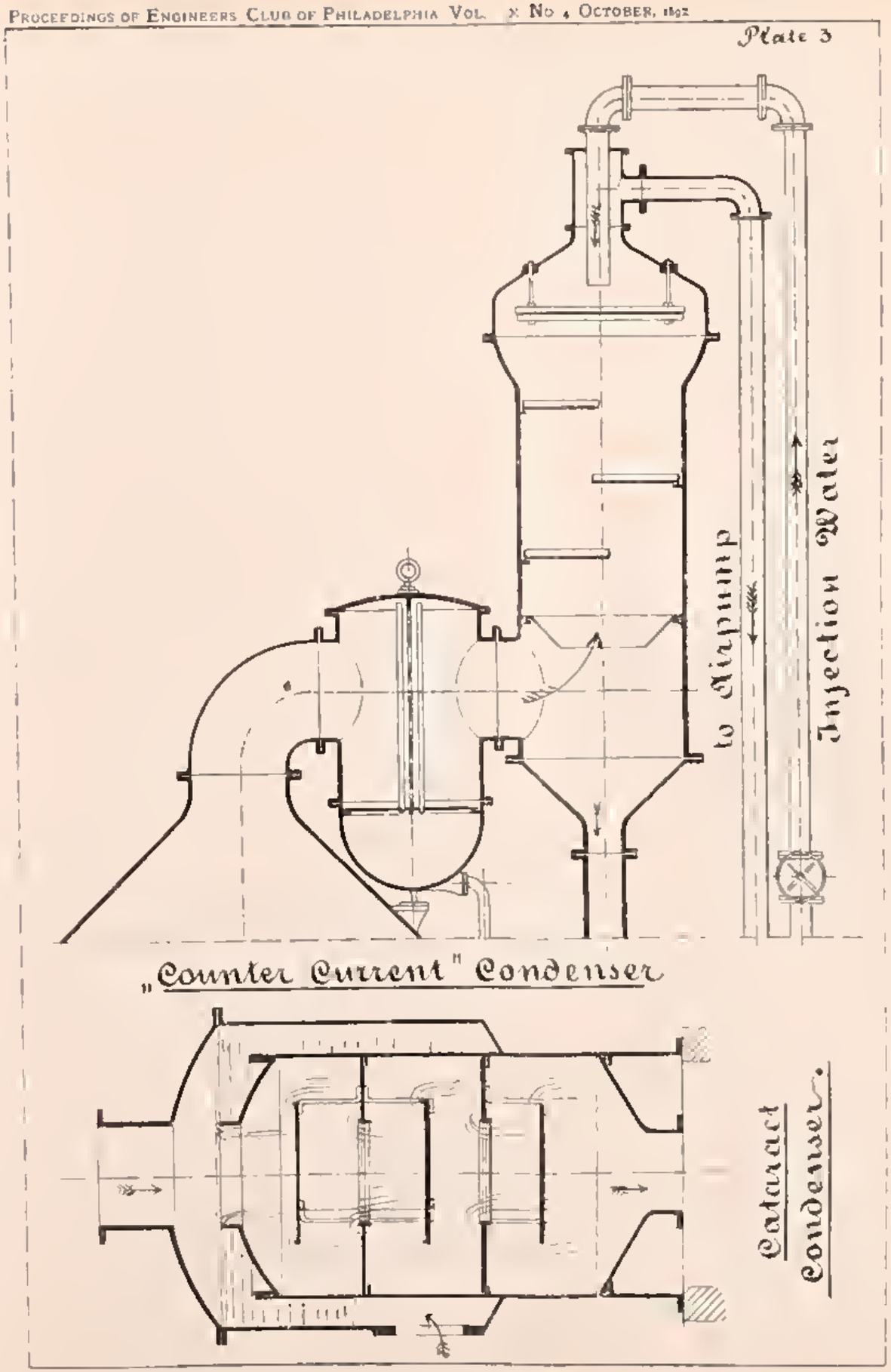

to Airpump
Injection Water
„Counter Current" Condenser
Cataract Condenser.

Plate 4.

„Parallel Current"
Condenser.
Injection Water
Airpump
Heater with Jet Condenser
Injection
Airpump
Water

Plate. 5

Pressures in Pounds
Temperatures Degrees Fahrenheit
Cubic feet 1 lb of Water
Volumes of Water and Steam
Temperatures
126.2°
163.4°
200.6°
37.2°
37.2°
37.2°
Steam 267.8°
Pounds
Gauge 16.
Inches Vacuum.

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XVII.

RECENT EXPERIMENTS ON THE FLOW OF WATER OVER WEIRS.

By M. Bazin, Inspector-General of Bridges and Highways.

Reprint from Annales des Ponts et Chaussées, January, 1890.

Translated by Arthur Marichal and John C. Trautwine, Jr., Members of the Club.

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* m_2	Coefficient: for weir *I.* m	Coefficient: for vertical weir 1.13m. high. M	$\frac{m}{M}$
Series No. 18.—Inclination $\frac{1}{4}$ down-stream. November and December, 1888.								
	Temperature of water: 10° C. (50° Fahr.)							
	Weir *I:* Height, 1.133 meter; Length, $l = 1.994$ meter; Weir *C:* " 0.502 " " $L = 1.995$ " $\frac{L}{l} = 1.0005$.							
	Meter.	Meter.						
1	0.0669	0.0695	1.0389	1.0594	0.4416	0.4678	0.4409	1.061
2	0.0881	0.0918	1.0420	1.0642	0.4368	0.4648	0.4356	1.067
3	0.1081	0.1132	1.0472	1.0722	0.4351	0.4665	0.4325	1.079
4	0.1283	0.1347	1.0499	1.0763	0.4352	0.4684	0.4302	1.089
5	0.1412	0.1490	1.0552	1.0845	0.4359	0.4727	0.4291	1.102
6	0.1664	0.1754	1.0541	1.0828	0.4374	0.4736	0.4275	1.108
7	0.1858	0.1953	1.0511	1.0782	0.4388	0.4731	0.4267	1.109
8	0.2075	0.2169	1.0453	1.0692	0.4406	0.4711	0.4261	1.106
9	0.2215	0.2314	1.0447	1.0683	0.4418	0.4720	0.4259	1.108
10	0.2462	0.2554	1.0374	1.0572	0.4441	0.4695	0.4259	1.102
11	0.2655	0.2747	1.0347	1.0530	0.4460	0.4696	0.4261	1.102
12	0.2865	0.2960	1.0332	1.0507	0.4480	0.4707	0.4264	1.104
13	0.3008	0.3115	1.0356	1.0544	0.4496	0.4741	0.4266	1.111
14	0.3263	0.3358	1.0291	1.0445	0.4520	0.4721	0.4270	1.106
15	0.3391	0.3508	1.0345	1.0527	0.4535	0.4774	0.4273	1.117
16	0.3641	0.3738	1.0266	1.0407	0.4558	0.4744	0.4278	1.109
17	0.3806	0.3906	1.0263	1.0402	0.4576	0.4760	0.4281	1.112
18	0.4043	0.4133	1.0223	1.0342	0.4598	0.4755	0.4287	1.109
19	0.4220	0.4283	1.0149	1.0229	0.4614	0.4720	0.4292	1.100
20	0.4395	0.4462	1.0152	1.0234	0.4632	0.4740	0.4297	1.103

SERIES NOS. 19 TO 22.

Inclined weir (I), 0.50 meter high, placed 46 meters below the head of the channel.
Vertical weir (C), 1.13 meter high, placed at the head of the channel.

Experiment No.	Heads observed on weir I. h	Heads observed on weir C. H	Ratios $\frac{H}{h}$	Ratios $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient for weir C. M	Coefficient for weir I m	Coefficient for vertical weir 0.50 m. high. m_2	$\frac{m}{m_2}$
Series No. 19.—inclination 45° up-stream. October, 1888. Temperature of water: 8° C. (46.4° Fahr.) Weir I: Height, 0.502 meter; Length, $l = 1.996$ meter $\}$ $\frac{L}{l} = 1.0005$. Weir C: " 1.135 " " $L = 1.997$ " $\}$								
	Meters.	Meters.						
1	0.2276	0.2189	0.9618	0.9437	0.4259	0.4019	0.4415	0.910
2	0.2471	0 2413	0.9765	0.9654	0.4258	0.4111	0.4433	0.927
3	0.2662	0.2611	0.9808	0.9718	0.4260	0.4140	0.4452	0.930
4	0.2878	0.2812	0.9771	0.9663	0.4263	0.4119	0.4473	0.921
5	0.3041	0.2991	0.9836	0.9760	0.4266	0.4164	0.4488	0.928
6	0.3240	0 3197	0.9867	0.9806	0.4269	0.4186	0.4508	0.929
7	0.3423	0.3388	0.9898	0.9852	0.4273	0.4210	0.4526	0.930
8	0.3631	0.3601	0.9917	0.9881	0.4277	0.4226	0.4547	0.929
9	0.3799	0.3781	0.9953	0.9935	0.4281	0.4253	0.4564	0.932
10	0.3990	0.3983	0.9982	0.9978	0.4286	0.4277	0.4584	0.933
11	0.4159	0.4174	1.0036	1.0059	0.4290	0.4315	0.4601	0.938
12	0.4327	0.4350	1.0053	1.0085	0.4296	0.4333	0.4619	0.938
13	0.4516	0.4549	1.0073	1.0115	0.4300	0.4349	0.4638	0.938
Series No. 20.—inclination $\frac{3}{1}$ up-stream. October, 1888. Temperature of water: 8° C. (46.4° Fahr.) Weir I: Height, 0.501 meter; Length, $l = 1.996$ meter $\}$ $\frac{L}{l} = 1.0005$. Weir C: " 1.134 " " $L = 1.997$ " $\}$								
1	0.1050	0.1021	0.9724	0.9594	0.4333	0.4157	0.4355	0.955
2	0.1249	0.1217	0.9744	0.9623	0.4308	0.4146	0.4350	0.953
3	0.1449	0.1423	0.9820	0.9736	0.4290	0.4177	0.4356	0.959
4	0.1640	0.1610	0.9817	0.9732	0.4278	0.4163	0.4366	0.954
5	0.1846	0.1822	0.9870	0 9811	0.4268	0.4187	0.4380	0.956
6	0.2018	0.1996	0.9891	0.9842	0.4262	0.4195	0.4393	0.955
7	0.2244	0.2227	0.9924	0.9891	0.4259	0.4213	0.4413	0.955
8	0.2418	0.2407	0.9955	0.9938	0.4258	0.4232	0.4428	0.956
9	0.2594	0.2598	1.0015	1.0028	0.4260	0.4272	0.4445	0.961
10	0.2816	0 2813	0.9989	0.9988	0.4263	0.4258	0.4467	0.953
11	0.2989	0.3006	1.0057	1.0091	0.4266	0.4305	0.4483	0.960
12	0.3175	0.3191	1.0050	1.0080	0.4269	0.4303	0.4502	0.956
13	0.3344	0.3382	1.0114	1.0177	0.4273	0.4349	0.4518	0.963
14	0.3567	0.3605	1.0107	1.0166	0.4277	0.4348	0.4541	0.957
15	0.3740	0.3794	1.0144	1.0222	0.4281	0.4376	0.4558	0.960
16	0.3917	0.3978	1.0156	1.0240	0.4286	0.4389	0.4577	0.959
17	0.4084	0.4174	1.0220	1.0336	0.4290	0.4434	0.4593	0 965
18	0.4254	0.4343	1.0209	1.0320	0.4295	0.4432	0.4611	0.961
19	0.4429	0.4545	1.0262	1.0401	0.4300	0.4472	0.4629	0.966

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir, 0.50m. high. m_2	$\frac{m}{m_2}$
	Meters.	Meters.						
1	0.0827	0.0837	1.0121	1.0182	0.4365	0.4444	0.4385	1.013
2	0.1023	0.1038	1.0147	1.0221	0.4331	0.4427	0.4356	1.016
3	0.1223	0.1246	1.0188	1.0283	0.4305	0.4427	0.4349	1.018
4	0.1380	0.1414	1.0246	1.0371	0.4291	0.4450	0.4353	1.022
5	0.1582	0.1623	1.0259	1.0391	0.4277	0.4444	0.4363	1.019
6	0.1773	0.1827	1.0305	1.0461	0.4268	0.4465	0.4375	1.021
7	0.1959	0.2022	1.0322	1.0487	0.4262	0.4470	0.4389	1.018
8	0.2160	0.2238	1.0361	1.0546	0.4259	0.4492	0.4405	1.020
9	0.2323	0.2410	1.0375	1.0568	0.4258	0.4500	0.4419	1.018
10	0.2505	0.2610	1.0419	1.0635	0.4260	0.4531	0.4437	1.021
11	0.2698	0.2816	1.0437	1.0663	0.4263	0.4546	0.4455	1.020
12	0.2881	0.3014	1.0462	1.0701	0.4266	0.4565	0.4473	1.021
13	0.3056	0.3207	1.0494	1.0750	0.4269	0.4589	0.4490	1.022
14	0.3237	0.3395	1.0488	1.0741	0.4273	0.4590	0.4508	1.018
15	0.3441	0.3611	1.0494	1.0750	0.4277	0.4598	0.4528	1.015
16	0.3621	0.3803	1.0503	1.0764	0.4281	0.4608	0.4546	1.014
17	0.3798	0.4002	1.0537	1.0816	0.4286	0.4636	0.4564	1.016
18	0.3927	0.4150	1.0568	1.0864	0.4290	0.4661	0.4578	1.018
19	0.4115	0.4352	1.0576	1.0876	0.4296	0.4672	0.4597	1.016
20	0.4313	0.4574	1.0605	1.0921	0.4301	0.4697	0.4617	1.017

SERIES No. 21.—INCLINATION $\frac{3}{1}$ DOWN-STREAM. NOVEMBER, 1888.

Temperature of water: 9.5° C. (49.1° Fahr.)

Weir *I:* Height, 0.508 meter; Length, $l = 1.996$ meter
Weir *C:* " 1.135 " " $L = 1.996$ " } $\frac{L}{l} = 1.$

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir 0.50m. high. m_2	$\frac{m}{m_2}$
	Meters.	Meters.						
1	0 0622	0.0646	1.0386	1.0585	0.4416	0.4674	0.4438	1.053
2	0.0769	0.0823	1.0702	1.1071	0.4367	0.4835	0.4397	1.100
3	0.0970	0.1025	1.0567	1.0862	0.4333	0.4707	0.4361	1.079
4	0.1150	0.1235	1.0739	1.1129	0.4307	0.4793	0.4351	1.102
5	0.1327	0.1421	1.0708	1.1081	0.4290	0.4754	0.4352	1.092
6	0.1509	0.1630	1.0802	1.1227	0.4277	0.4802	0.4359	1.102
7	0.1701	0.1832	1.0770	1.1177	0.4268	0.4770	0.4370	1.092
8	0.1855	0.2018	1.0879	1.1347	0.4262	0.4836	0.4381	1.104
9	0.2060	0.2235	1.0850	1.1302	0.4259	0.4814	0.4397	1.095
10	0.2213	0 2416	1.0917	1.1407	0.4258	0.4857	0.4410	1.101
11	0.2427	0.2638	1.0869	1.1331	0.4261	0.4828	0.4429	1.090
12	0.2581	0.2827	1.0953	1.1463	0.4263	0.4887	0.4444	1.100
13	0 2767	0.3018	1.0907	1.1391	0.4266	0.4859	0.4462	1.089
14	0.2927	0.3216	1.0987	1.1516	0.4269	0.4916	0.4477	1.098
15	0.3102	0.3408	1.0986	1.1515	0.4273	0.4920	0.4494	1.095
16	0.3287	0.3625	1.1028	1.1581	0.4278	0.4954	0.4513	1.098
17	0.3452	0.3801	1.1011	1.1554	0.4281	0.4946	0.4529	1.092
18	0.3621	0.3999	1.1044	1.1606	0.4286	0.4974	0.4546	1.094
19	0.3784	0.4184	1.1057	1.1627	0.4291	0.4989	0.4562	1.094
20	0.3942	0.4365	1.1073	1.1652	0.4296	0.5006	0.4579	1.093
21	0.4136	0.4582	1.1078	1.1660	0.4301	0.5015	0.4599	1.090

SERIES No. 22.—INCLINATION 45° DOWN-STREAM. OCTOBER, 1888.

Temperature of water: 8° C. (46.4° Fahr.)

Weir *I:* Height, 0.504 meter; Length, $l = 1.996$ meter
Weir *C:* " 1.135 " " $L = 1.996$ " $\Big\}\ \frac{L}{l} = 1.$

SERIES NOS. 23 to 30.

Inclined weirs (I), 0.35 meter high, placed 46 meters below the head of the channel.
Vertical weir (C), 1.13 meter high, placed at the head of the channel.

Experiment No.	Heads observed: on weir I. h	Heads observed: on weir C. H	Ratios. $\frac{H}{h}$	Ratios. $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir C. M	Coefficient: for weir I. m	Coefficient: for vertical weir 0.35m. high. m_3	$\frac{m}{m_3}$

Series No. 23.—inclination 45° up-stream. November, 1888.

Temperature of water: 9° C. (48.2° Fahr.).
Weir I: Height, 0.359 meter; Length, $l = 1.996$ meter } $\frac{L}{l} = 1.$
Weir C: " 1.135 " " $L = 1.996$ " }

	Meters.	Meters.						
1	0.2054	0.2042	0.9942	0.9913	0.4261	0.4224	0.4500	0.939
2	0.2235	0.2226	0.9960	0.9940	0.4259	0.4233	0.4525	0.935
3	0.2430	0.2431	1.0004	1.0006	0.4258	0.4261	0.4554	0.936
4	0.2595	0.2618	1.0089	1.0134	0.4260	0.4317	0.4578	0.943
5	0.2807	0.2833	1.0093	1.0140	0.4263	0.4323	0.4609	0.938
6	0.2960	0.2997	1.0125	1.0188	0.4266	0.4346	0.4632	0.938
7	0.3166	0.3223	1.0180	1.0271	0.4269	0.4385	0.4664	0.940
8	0.3342	0.3395	1.0159	1.0239	0.4273	0.4375	0.4691	0.933
9	0.3536	0.3623	1.0246	1.0371	0.4277	0.4436	0.4721	0.940
10	0.3708	0.3806	1.0264	1.0399	0.4281	0.4452	0.4748	0.938
11	0.3882	0.4003	1.0312	1.0472	0.4286	0.4488	0.4775	0.940
12	0.4059	0.4190	1.0323	1.0488	0.4291	0.4500	0.4803	0.937
13	0.4204	0.4354	1.0357	1.0540	0.4296	0.4528	0.4826	0.938
14	0.4392	0.4560	1.0383	1.0580	0.4301	0.4550	0.4856	0.937

Experiment No.	Heads Observed: on weir *I.* h	Heads Observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir 0.35m. high m_3	$\frac{m}{m_3}$
	Meters.	Meters.						
1	0.1637	0.1615	0.9866	0.9795	0.4277	0.4189	0.4442	0.943
2	0.1850	0.1827	0.9876	0.9810	0.4268	0.4187	0 4470	0.937
3	0.2028	0.2025	0.9985	0.9973	0.4261	0.4249	0.4496	0.945
4	0.2222	0.2227	1.0023	1.0030	0.4259	0.4272	0.4523	0.945
5	0.2399	0.2419	1.0083	1.0120	0.4258	0.4309	0.4549	0.947
6	0.2589	0.2611	1.0085	1.0123	0.4260	0.4312	0.4577	0.942
7	0.2756	0.2803	1.0171	1.0253	0.4263	0.4371	0.4601	0 950
8	0.2948	0.3005	1.0193	1.0286	0.4266	0.4388	0.4630	0.948
9	0.3131	0.3202	1.0227	1.0337	0.4269	0.4413	0.4658	0.947
10	0.3315	0.3393	1.0235	1.0349	0 4273	0.4422	0.4686	0.944
11	0.3494	0.3591	1.0278	1.0414	0.4277	0.4454	0.4714	0.945
12	0.3690	0.3808	1.0320	1.0479	0.4281	0.4486	0.4745	0.945
13	0.3851	0.3995	1.0374	1.0561	0.4286	0.4526	0.4770	0.949
14	0.4039	0.4201	1.0401	1.0602	0.4291	0.4549	0.4800	0.948
15	0.4184	0.4355	1.0409	1.0615	0.4296	0.4560	0.4823	0.945
16	0.4333	0.4526	1.0445	1.0670	0.4300	0.4588	0.4846	0.947

SERIES NO. 24.

INCLINATION $\frac{3}{2}$ UP-STREAM. NOVEMBER, 1888.

Temperature of water: 9° C. (48.2° Fahr.)

Weir *I:* Height, 0.357 meter; Length, $l = 1.997$ meter
Weir *C:* " 1.135 " " $L = 1.996$ " $\Big\} \frac{L}{l} = 0.9995.$

SERIES NO. 25.

INCLINATION $\frac{3}{1}$ UP-STREAM. NOVEMBER, 1888.

Temperature of water: 9° C. (48.2° Fahr.)

Weir *I:* Height, 0.359 meter; Length, Nov. 17, $l_1 = 1.997$ meter; Nov. 19, $l_2 = 1.996$ " $\Big\} \frac{L}{l_1} = 0.9995.$
Weir *C:* " 1.135 " " $L = 1.996$ " $\Big\} \frac{L}{l_2} = 1.$

1	0.0851	0.0836	0.9824	0.9732	0.4365	0.4248	0.4396	0.966
2	0.1020	0.1008	0.9882	0.9824	0.4335	0.4259	0.4389	0.970
3	0.1248	0.1246	0.9984	0.9971	0.4305	0.4293	0.4399	0.976
4	0.1411	0.1413	1.0014	1.0021	0.4291	0.4300	0.4414	0.974
5	0.1636	0.1638	1.0012	1.0013	0.4276	0.4282	0.4442	0.964
6	0.1801	0.1813	1.0067	1.0101	0.4268	0.4311	0.4463	0.966
7	0.2016	0.2038	1.0109	1.0159	0.4261	0.4329	0.4494	0.963
8	0.2176	0.2206	1.0138	1.0208	0.4259	0.4348	0.4517	0.963
9	0.2375	0.2414	1.0164	1.0242	0.4258	0.4361	0.4546	0 959
10	0.2520	0.2588	1.0270	1.0408	0.4260	0.4434	0.4567	0.971
11	0.2752	0.2823	1.0258	1.0384	0.4263	0.4427	0.4601	0.962
12	0.2935	0.3030	1.0324	1.0490	0.4267	0 4476	0.4628	0.967
13	0.3110	0.3211	1.0325	1.0486	0.4269	0.4476	0.4655	0.962
14	0.3276	0.3404	1.0391	1.0592	0.4273	0.4526	0.4680	0 967
15	0.3473	0.3615	1.0409	1.0614	0.4277	0.4540	0 4711	0.964
16	0.3672	0.3827	1.0422	1.0640	0.4282	0.4556	0.4743	0.961
17	0.3846	0.4020	1.0452	1.0680	0 4286	0.4578	0.4769	0.960
18	0.4013	0.4215	1.0503	1.0764	0.4291	0.4619	0.4796	0.963
19	0.4151	0.4383	1.0559	1.0845	0.4296	0.4659	0.4818	0.967
20	0.4305	0.4535	1.0534	1.0812	0.4300	0.4649	0.4842	0.960

Experiment No.	Heads Observed: on weir *I.* h	Heads Observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir 0.35m. high. m_3	$\frac{m}{m_3}$
	Meters.	Meters.						
1	0.0636	0.0642	1.0094	1.0141	0.4418	0.4480	0 4444	1.008
2	0.0803	0.0827	1.0299	1.0452	0.4367	0.4564	0.4403	1.037
3	0.1017	0.1041	1.0236	1.0356	0.4330	0.4484	0.4389	1.022
4	0 1178	0.1214	1.0306	1 0463	0.4309	0.4509	0.4395	1.026
5	0.1379	0.1426	1.0341	1.0516	0.4290	0.4511	0.4411	1.023
6	0.1563	0.1623	1 0384	1.0582	0.4277	0.4526	0.4432	1.021
7	0.1753	0.1821	1.0388	1.0588	0.4268	0.4519	0.4457	1.014
8	0,1909	0.1997	1.0461	1.0699	0.4262	0.4560	0.4478	1.018
9	0.2117	0.2223	1.0501	1.0761	0.4259	0.4583	0.4508	1.017
10	0.2269	0.2392	1.0542	1.0824	0.4258	0.4609	0.4530	1.017
11	0.2475	0.2620	1.0586	1.0892	0.4260	0.4640	0.4560	1.018
12	0.2630	0.2793	1.0620	1.0944	0.4263	0.4665	0.4583	1.018
13	0.2829	0.3012	1.0647	1.0986	0.4266	0.4687	0.4612	1.016
14	0.2982	0.3190	1.0698	1.1065	0.4269	0.4724	0.4635	1.019
15	0.3183	0.3407	1.0704	1.1074	0.4273	0.4732	0.4666	1.014
16	0.3341	0.3589	1.0742	1.1133	0.4277	0.4762	0 4691	1.015
17	0.3527	0.3799	1.0771	1.1179	0.4281	0.4786	0.4719	1.014
18	0.3686	0.3977	1.0789	1.1207	0.4286	0.4803	0.4745	1.012
19	0.3862	0.4183	1.0831	1.1272	0.4290	0.4836	0.4772	1.013
20	0.4006	0.4346	1.0849	1.1300	0.4295	0.4853	0.4795	1.012
21	0.4104	0.4447	1.0836	1.1280	0.4298	0.4848	0.4811	1.008

SERIES NO. 26.

INCLINATION $\frac{3}{1}$ DOWN-STREAM. NOVEMBER, 1888.

Temperature of water: 8.5° C. (47.3° Fahr.)

Weir *I:* Height, 0.358 meter; Length, $l = 1.996$ meter } $\frac{L}{l} = 1.$
Weir *C:* " 1.135 " " " $L = 1.996$ " }

Experiment No.	Heads Observed: on weir *I.* h	Heads Observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir 0.35m. high. m_3	$\frac{m}{m_3}$
			SERIES NO. 27.					
			INCLINATION $\frac{3}{2}$ DOWN-STREAM. NOVEMBER, 1888.					
			Temperature of water: 9° C. (48.2° Fahr.)					
			Weir *I:* Height, 0.351 meter; Length, $l = 1.997$ meter } $\frac{L}{l} = 1.$					
			Weir *C:* " 1.135 " " " $L = 1.997$ " }					
	Meters.	Meters.						
1	0.0594	0.0620	1.0438	1.0664	0.4425	0.4719	0.4457	1.059
2	0.0782	0.0820	1.0486	1.0738	0.4368	0.4690	0.4407	1.064
3	0.0975	0.1028	1.0544	1.0827	0.4332	0.4690	0.4388	1.069
4	0.1145	0.1211	1.0576	1.0876	0.4309	0.4686	0.4393	1.067
5	0.1328	0.1414	1.0648	1.0988	0.4291	0.4715	0.4406	1.070
6	0.1498	0.1595	1.0648	1.0988	0.4278	0.4701	0.4424	1.063
7	0.1702	0.1824	1.0717	1.1095	0.4268	0.4735	0.4450	1.064
8	0.1871	0.2017	1.0780	1.1193	0.4262	0.4770	0.4473	1.066
9	0.2057	0.2227	1.0826	1.1264	0.4259	0.4797	0.4500	1.066
10	0.2210	0.2395	1.0837	1.1281	0.4258	0.4803	0.4522	1.062
11	0.2382	0.2596	1.0898	1.1377	0.4260	0.4847	0.4546	1.066
12	0.2563	0.2799	1.0921	1.1413	0.4263	0.4865	0.4573	1.064
13	0.2727	0.2981	1.0931	1.1429	0.4266	0.4876	0.4597	1.061
14	0.2911	0.3180	1.0924	1.1418	0.4269	0.4874	0.4625	1.054
15	0.3070	0.3380	1.1010	1.1553	0.4273	0.4937	0.4649	1.062
16	0.3270	0.3604	1.1021	1.1570	0.4277	0.4948	0.4679	1.058
17	0.3438	0.3793	1.1033	1.1589	0.4281	0.4961	0.4706	1.054
18	0.3599	0.3969	1.1028	1.1581	0.4285	0.4962	0.4731	1.049
19	0.3759	0.4171	1.1096	1.1688	0.4290	0.5014	0.4756	1.054
20	0.3918	0.4350	1.1103	1.1699	0.4295	0.5025	0.4781	1.051
21	0.4084	0.4551	1.1143	1.1763	0.4301	0.5059	0.4807	1.052

Experiment No.	Heads Observed: on weir *I.* h	Heads Observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir 0.35m. high. m_3	m / m_3
	Meters.	Meters.						
1	0.0601	0.0639	1.0632	1.0963	0.4419	0.4845	0.4455	1.088
2	0.0765	0.0815	1.0654	1.0997	0.4369	0.4805	0.4411	1.089
3	0.0963	0.1025	1.0644	1.0981	0.4332	0.4757	0.4389	1.084
4	0.1135	0.1225	1.0793	1.1213	0.4307	0.4829	0.4393	1.099
5	0.1311	0.1419	1.0824	1.1261	0.4290	0.4831	0.4404	1.097
6	0.1481	0.1610	1.0871	1.1335	0.4277	0.4848	0.4422	1.096
7	0.1674	0.1820	1.0872	1.1336	0.4268	0.4838	0.4447	1.088
8	0.1830	0.2001	1.0934	1.1433	0.4262	0.4873	0.4467	1.091
9	0.2030	0.2227	1.0970	1.1490	0.4259	0.4894	0.4496	1.089
10	0.2171	0.2391	1.1013	1.1557	0.4258	0.4921	0.4516	1.090
11	0.2365	0.2614	1.1053	1.1620	0.4260	0.4950	0 4544	1.089
12	0.2516	0.2790	1.1089	1.1677	0.4263	0.4978	0.4566	1.090
13	0.2701	0.3001	1.1111	1.1712	0.4266	0.4996	0.4593	1.088
14	0.2877	0.3198	1.1116	1.1720	0.4269	0.5003	0.4620	1.083
15	0.3029	0 3376	1.1146	1.1767	0.4273	0.5028	0.4642	1.083
16	0.3221	0.3602	1.1183	1.1826	0.4277	0.5058	0.4672	1.083
17	0.3390	0.3799	1.1206	1.1862	0.4281	0.5078	0.4698	1.081
18	0.3550	0.3986	1.1228	1.1897	0.4286	0.5099	0.4723	1.080
19	0.3715	0.4190	1.1279	1.1979	0.4291	0.5140	0.4749	1.082
20	0.3863	0.4360	1.1287	1.1991	0.4296	0.5151	0.4772	1.079
21	0.4050	0.4577	1.1301	1.2014	0.4301	0.5167	0.4802	1.076

SERIES NO. 28.

INCLINATION 45° DOWN-STREAM. NOVEMBER, 1888.

Temperature of water, 8.5° C. (47.3° Fahr.)

Weir *I:* Height, 0.352 meter; Length, $l = 1.996$ meter
Weir *C:* " 1.135 " " $L = 1.996$ " } $\frac{L}{l} = 1.$

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir 0.35m. high. m_3	$\frac{m}{m_3}$
	Meters.	Meters.						
1	0.0568	0.0604	1.0634	1.0975	0.4431	0.4863	0.4468	1.088
2	0.0753	0.0805	1.0691	1.1063	0.4371	0.4835	0.4413	1.096
3	0.0956	0.1030	1.0774	1.1192	0.4332	0.4848	0.4389	1.105
4	0.1154	0.1250	1.0832	1.1282	0.4305	0.4857	0.4394	1.105
5	0.1305	0.1426	1.0927	1.1431	0.4290	0.4904	0.4404	1.114
6	0.1508	0.1649	1.0935	1.1444	0.4276	0.4893	0.4425	1.106
7	0.1669	0.1837	1.1007	1.1557	0.4268	0.4933	0.4446	1.110
8	0.1830	0.2025	1.1066	1.1650	0.4261	0.4964	0.4467	1.111
9	0.2023	0.2242	1.1083	1.1677	0.4259	0.4973	0.4495	1.106
10	0.2170	0.2416	1.1134	1.1758	0.4258	0.5007	0.4516	1.109
11	0.2372	0.2654	1.1189	1.1845	0.4261	0.5047	0.4545	1.110
12	0.2510	0.2819	1.1231	1.1912	0.4263	0.5078	0.4566	1.112
13	0.2703	0.3042	1.1254	1.1948	0.4267	0.5098	0.4593	1.110
14	0.2852	0.3209	1.1252	1.1945	0.4269	0.5099	0.4616	1.105
15	0.3040	0.3430	1.1283	1.1995	0.4274	0.5127	0.4644	1.104
16	0.3210	0.3637	1.1330	1.2070	0.4278	0.5164	0.4671	1.106
17	0.3376	0.3833	1.1354	1.2108	0.4282	0.5185	0.4696	1.104
18	0.3528	0.4011	1.1369	1.2132	0.4286	0.5200	0.4719	1.102
19	0.3721	0.4233	1.1376	1.2143	0.4292	0.5212	0.4750	1.097
20	0.3839	0.4399	1.1459	1.2276	0.4297	0.5275	0.4768	1.106
21	0.4047	0.4626	1.1431	1.2231	0.4303	0.5263	0.4802	1.096

SERIES NO. 29.

INCLINATION $\frac{1}{2}$ DOWN-STREAM. NOVEMBER, 1888.

Temperature of water: 8° C. (46.4° Fahr.)

Weir *I:* Height, 0.351 meter; Length, $l = 1.996$ meter } $\frac{L}{l} = 1.0008.$
Weir *C:* " 1.135 " " " $L = 1.9975$ " }

Experiment No.	Heads observed: on weir *I.* h	Heads observed: on weir *C.* H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: for weir *C.* M	Coefficient: for weir *I.* m	Coefficient: for vertical weir 0.35m. high. m_3	$\frac{m}{m_3}$

SERIES NO. 30.

INCLINATION $\frac{1}{4}$ DOWN-STREAM. OCTOBER AND NOVEMBER, 1888.

Temperature of water: 8° C. (46.4° Fahr.)

Weir *I:* Height, 0.348 meter; Length, Oct. 31, $l_1 = 1.994$ meter; Nov. 3, $l_2 = 1.996$ " $\left.\right\} \frac{L}{l_1} = 1.0010.$

Weir *C:* ", 1.135 " " . . . . $L = 1.996$ " $\left.\right\} \frac{L}{l_2} = 1.$

	Meters.	Meters.						
1	0.0616	0.0636	1.0325	1.0491	0.4420	0.4637	0.4450	1.042
2	0.0808	0.0848	1.0495	1.0752	0.4362	0.4690	0.4402	1.065
3	0.0980	0.1035	1.0561	1.0864	0.4331	0.4705	0.4388	1.072
4	0.1164	0.1235	1.0610	1.0929	0.4306	0.4706	0.4394	1.071
5	0.1332	0.1421	1.0668	1.1019	0.4290	0.4727	0.4406	1.073
6	0.1528	0.1629	1.0661	1.1008	0.4277	0.4708	0.4428	1.063
7	0.1694	0.1822	1.0756	1.1155	0.4268	0.4761	0.4449	1.070
8	0.1866	0.2016	1.0804	1.1241	0.4262	0.4791	0.4472	1.071
9	0.2046	0.2221	1.0855	1.1311	0.4259	0.4817	0.4498	1.071
10	0.2212	0.2408	1.0886	1.1369	0.4258	0.4841	0.4522	1.071
11	0.2398	0.2619	1.0922	1.1414	0.4260	0.4862	0.4549	1.069
12	0.2562	0.2818	1.0999	1.1547	0.4263	0.4922	0.4573	1.076
13	0.2729	0.2995	1.0975	1.1498	0.4266	0.4905	0.4597	1.067
14	0.2902	0.3203	1.1037	1.1607	0.4269	0.4955	0.4623	1.072
15	0.3092	0.3418	1.1054	1.1622	0.4273	0.4966	0.4652	1.067
16	0.3252	0.3621	1.1135	1.1762	0.4277	0.5031	0.4675	1.076
17	0.3414	0.3794	1.1113	1.1715	0.4281	0.5015	0.4702	1.067
18	0.3562	0.3985	1.1188	1.1846	0.4286	0.5077	0.4725	1.075
19	0.3739	0.4180	1.1179	1.1820	0.4290	0.5071	0.4753	1.067
20	0.3898	0.4356	1.1175	1.1814	0.4296	0.5075	0.4778	1.062
21	0.4049	0.4530	1.1188	1.1834	0.4300	0.5089	0.4802	1.060

In order to facilitate the comparisons, the last column of each table is made to show for each experiment the ratio $\frac{m}{m_3}$ between the coefficient m for the inclined weir and that (m_3) corresponding to the same head on a vertical weir of the same height. An inspection of these ratios brings to light at once an important fact. If we except the first two or three experiments of each series, where these ratios increase, we readily see that they are sensibly constant for a given inclination. Grouping the experiments in the increasing order of the heads and calculating their mean values, we obtain the following table:

Table of Mean Values of the Ratios Given in the Foregoing Tables.

m = coefficient for inclined weirs.
M = " " vertical weir 1.13 meter (3.7 feet) high.
m_2 = " " " " 0.50 " (1.64 ft.) "
m_3 = " " " " 0.35 " (1.15 ft.) "

Heads.	Inclination							
	up-stream.			down-stream.				
	$\frac{1}{1}$	$\frac{3}{2}$	$\frac{3}{1}$	$\frac{3}{1}$	$\frac{3}{2}$	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{4}$
Weir 1.13 meter high.								
	$\frac{m}{M}$	$\frac{m}{M}$	$\frac{m}{M}$	$\frac{m}{M}$	$\frac{m}{M}$	$\frac{m}{M}$	$\frac{m}{M}$	$\frac{m}{M}$
0.10m. to 0.15m.	. . .		. . .	1.044	1.083	1.109	1.136	1.090
0.15m. to 0.25m.	. . .	0.936	0.953	1.045	1.087	1.117	1.136	1.107
0.25m. to 0.35m.	0.924	0.935	0.961	1.048	1.090	1.118	1.137	1.108
0.35m. to 0.45m.	0.928	0.934	0.964	1.047	1.086	1.114	1.139	1.107
Means	0.926	0.935	0.959	1.046	1.086	1.115	1.137	1.103
Weir 0.50 meter high.								
	$\frac{m}{m_2}$	$\frac{m}{m_2}$	$\frac{m}{m_2}$	$\frac{m}{m_2}$	$\frac{m}{m_2}$	$\frac{m}{m_2}$	$\frac{m}{m_2}$	$\frac{m}{m_2}$
0.10m. to 0.15m.	. . .	.	0.956	1.019	. . .	1.097	. . .	. .
0.15m. to 0.25m.	. .	. .	0.955	1.019	.	1.097	. . .	. . .
0.25m. to 0.35m.	0.928	. . .	0 959	1.019	. . .	1.095	. . .	. . .
0.35m. to 0.45m.	0.934	. . .	0.961	1.016	. . .	1.093	. . .	. . .
Means	0.931	. . .	0.958	1.018	. . .	1.095	. . .	. . .
Weir 0.35 meter high.								
	$\frac{m}{m_3}$	$\frac{m}{m_3}$	$\frac{m}{m_3}$	$\frac{m}{m_3}$	$\frac{m}{m_3}$	$\frac{m}{m_3}$	$\frac{m}{m_3}$	$\frac{m}{m_3}$
0.10m. to 0.15m.	. . .	. . .	0.973	1.024	1.067	1.097	1.109	1.072
0.15m. to 0.25m.	0.937	0.943	0.963	1.017	1.065	1.089	1.109	1.069
0.25m. to 0.35m.	0.938	0.946	0.966	1.016	1.059	1.085	1.107	1.071
0.35m. to 0.45m.	0.938	0.947	0.962	1.012	1.052	1.079	1.100	1.066
Means	0.938	0.945	0.966	1.017	1.061	1.088	1.106	1.069

This table shows:

(1) That the ratios increase from the greatest inclination up-stream until the down-stream inclination becomes $\frac{1}{2}$, in the neigh-

borhood of which the ratio reaches a maximum, diminishing again when the down-stream inclination reaches $\frac{1}{4}$.

(2) That for a given head h the ratios approximate to unity as the height p of the weir decreases.

Form of the Nappe in Inclined Weirs.

The inclination of the weir considerably modifies the form of the nappe. As we incline the weir progressively up-stream from the vertical, the elevation of the under surface increases gradually, and the ratio $\frac{\epsilon}{h}$, the value of which for the vertical weir 1.13 m. (3.7 feet) high is 0.11, reaches 0.16 for an up-stream inclination of 45°. At the same time the initial tangent of the curve at the crest of the weir rises. It becomes vertical for a certain inclination in the neighborhood of $\frac{3}{1}$, after which, for greater inclinations, it is directed up-stream, so that a portion of the lower surface of the nappe is found behind (or up-stream from) the crest.* The opposite effect is produced if the weir is inclined down-stream; $\frac{\epsilon}{h}$ then diminishes gradually to zero, while the initial tangent is lowered more and more, and finally becomes nearly horizontal. The complete profile of the nappes has been taken for a great number of different heads upon the weirs 1.13 and 0.35 m. (3.7 and 1.15 feet) high, as follows:†

Weir 1.13 m. (3.7 feet high).	Series No. 11, 5 profiles, heads from 0.30 to 0.45 m. (11.8 to 17.7 inches).
	Series Nos. 12 to 16, 6 profiles for each series, heads from 0.20 to 0.45 m. (7.87 to 17.7 inches).
	Series Nos. 17 and 18, 3 profiles for each series, heads from 0.20 to 0.40 m. (7.87 to 15.75 inches).
Weir 0.35 m. (1.15 feet) high.	Series Nos. 23, 28, 29 and 30, 3 profiles for each series, heads from 0.20 to 0.40 m. (7.87 to 15.75 inches).
	Series Nos. 24 to 27, observations confined to that portion of the profile near the crest, heads from 0.17 to 0.40 m. (6.7 to 15.75 inches).

* In order to measure this part of the lower surface we have made use of a special knife, the point of which, turned horizontally, was brought into contact with the ascending part of the nappe behind the crest. (See Fig. 6, pl. 1.)

† The full tables of the ordinates will be found at the end of this paper.

It is upon the form of the *lower* surface of the nappe that the modifications produced by the inclination of the weir chiefly exhibit themselves. It will be seen at first sight that the summit of the curve approaches the crest of the weir in proportion as the latter is inclined down-stream. When it is vertical or inclined up-stream, the summit is found to correspond approximately to the abscissa $\frac{x}{h} = 0.25$. When the down-stream inclination reaches 45°, the summit recedes to the point whose abscissa is $\frac{x}{h} = 0.17$; and, finally, for the inclination $\frac{1}{4}$, the elevation disappears almost entirely, and the summit, which is now scarcely perceptible, is very close to the crest. Let us now substitute, as we did in the case of the vertical weir, the ratios $\frac{x}{h}$ and $\frac{y}{h}$ for the absolute values of x and y, and determine from a diagram of the curves the ordinate $\frac{\epsilon}{h}$ of the summit for each series of experiments.

Table Showing Variation of $\frac{\epsilon}{h}$ with Inclination and Height of Weir, and with the Head upon the Weir.

$$\frac{\epsilon}{h} = \frac{\text{elevation of summit of lower surface of nappe above crest.}}{\text{head.}}$$

Inclination of Weir.	Height, p, of Weir.	Number of Exp'ts made.	Heads, h.	$\gamma = \frac{h^2}{(p+h)^2}$	$\frac{\epsilon}{h}$
	Meters.		Meters.		
$\frac{1}{1}$ up stream	1.13	5	0.298 to 0.449	0.045 to 0.08	0.159
	0.35	1	0.205	0.13	0.128
	0.35	2	0.296 to 0.387	0.205 to 0.27	0 120
$\frac{3}{2}$ " "	1.13	6	0.200 to 0.456	0.025 to 0.08	0.150
	0.35	1	0.258	0.175	0.125
	0.35	2	0.311 to 0.368	0.22 to 0.26	0.117
$\frac{3}{1}$ " "	1.13	6	0.200 to 0.442	0.025 to 0.08	0.136
	0.35	2	0.178 to 0.252	0.110 to 0.17	0.119
	0.35	2	0.328 to 0.401	0.230 to 0.28	0.108
Vertical	1.13	18	0.152 to 0.449	0.015 to 0.08	0.112
	0.35	5	0.122 to 0.301	0.065 to 0.210	0.100
	0.35	3	0.353 to 0.450	0.250 to 0.315	0.097
$\frac{3}{1}$ down-stream . . .	1.13	5	0.250 to 0.447*	0.035 to 0.08	0.089
	0.35	2	0.175 to 0.249	0.110 to 0.17	0.084
	0.35	2	0.318 to 0.386	0.220 to 0.27	0.083
$\frac{3}{2}$ " " .	1.13	6	0.200 to 0.444	0.025 to 0.08	0.061
	0.35	2	0.186 to 0.266	0.120 to 0.18	0.058
	0.35	2	0.324 to 0.392	0.230 to 0.28	0.058
$\frac{1}{1}$ " " . . .	1.13	6	0.201 to 0.436	0.025 to 0.075	0.041
	0.35	2	0.201 to 0 302	0.130 to 0.215	0.041
	0 35	1	0.391	0.275	0.041
$\frac{1}{2}$ " " . . .	1.13	3	0.205 to 0.401	0.025 to 0.07	0 012
	0.35	2	0 203 to 0.299	0.135 to 0.21	0.018
	0.35	1	0.390	0.275	0 017
$\frac{1}{4}$ " " . . .	1.13	3	0.208 to 0.404	0.025 to 0 070	0.003
	0.35	2	0.202 to 0.299	0.135 to 0.215	0 004
	0.35	1	0.404	0.29	0.004

* Neglecting Experiment No. 1, which appeared to be erroneous

An examination of the preceding table shows that for a weir of constant height the ratio $\frac{\epsilon}{h}$ diminishes as the inclination of the weir changes from up-stream to down-stream. In the weir 1.13 m. (3.7 feet) high, where the effect of velocity of approach is scarcely perceptible, $\frac{\epsilon}{h}$ appears, for a given inclination, nearly independent of the head h; but if we turn to the weir 0.35 m. (1.15 feet) high, where the effect of velocity of approach is much greater, we see clearly that $\frac{\epsilon}{h}$ diminishes as the ratio $\frac{h}{p}$ of the head h to the height p of the weir increases. This diminution, very appreciable in weirs inclined up-stream, is, however, much less marked with weirs inclining down-stream. In fact, it disappears when the down-stream inclination reaches $\frac{1}{1}$ or 45°, and with down-stream inclinations of $\frac{1}{2}$ and $\frac{1}{4}$ it even gives place to a slight increase.

It will now be necessary to compare the coefficient m of discharge, already obtained, with the ratios $\frac{\epsilon}{h}$, in order to ascertain whether there exists a relation between these two quantities, and especially whether m varies proportionately with $\left(1 - \frac{\epsilon}{h}\right)^{\frac{3}{2}}$, as is indicated by the formula of M. Boussinesq. In order to simplify the calculation, we have reduced the ratios $\frac{m}{M}$ and $\frac{m}{m_3}$ of the coefficients to a single mean value determined between the same limits of head as the corresponding values of $\frac{\epsilon}{h}$. For the same reason, where the two values of $\frac{\epsilon}{h}$ obtained at a given inclination with the weir 0.35 m. (1.15 feet) high do not differ more than 0.002 or 0.003 ($\frac{2}{10}$ or $\frac{3}{10}$ of one per cent.), we have taken their *mean* value.

Inclination of Weir.	Weir 1.13 Meter High.					Weir 0.35 Meter High.				
	$\frac{\epsilon}{h}$	$\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}}$	$\frac{m^*}{M}$	R_1†	Differences.	$\frac{\epsilon}{h}$	$\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}}$	$\frac{m}{m_3}$‡	R_2 ⁂	Differences.
$\frac{1}{1}$ up-stream . .	0.159	0.771	0.927	0.921	—0.006	0.128 to 0.120	0.814 to 0.826	0.938	0.952 to 0.966	+0.014 to +0.028
$\frac{3}{2}$ " " . .	0.150	0.784	0.934	0.937	+0.003	0.125 to 0.117	0.818 to 0.830	0.946	0.957 to 0.971	+0.011 to +0.025
$\frac{3}{1}$ " " . .	0.136	0.803	0.961	0.959	—0.002	0.119 to 0.108	0.827 to 0.842	0.964	0.967 to 0.985	+0.003 to +0.021
Vertical	0.112	0.837	1.000	1.000	0	0.099	0.855	1.000	1.000	0
$\frac{3}{1}$ down-stream .	0.089	0.870	1.047	1.039	—0.008	0.083	0.878	1.016	1.027	+0.011
$\frac{3}{2}$ " " .	0.061	0.910	1.088	1.087	—0 001	0.058	0.914	1.059	1.069	+0.010
$\frac{1}{1}$ " " .	0.041	0.939	1.116	1.122	+0.006	0.041	0.939	1.085	1.098	+0.013
$\frac{1}{2}$ " " .	0.012	0.982	1.137	1.173	+0.036	0.018	0.973	1.106	1.138	+0.032
$\frac{1}{4}$ " " .	0.003	0.995	1.107	1.189	+0.082	0.004	0.994	1.070	1.163	+0.093

* $\frac{m}{M_1} = \frac{\text{coefficient for inclined weir 1.13 meter high.}}{\text{coefficient for vertical weir 1.13 meter high.}}$

† $R_1 = \frac{\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}} \text{ for inclined weir 1.13 meter high.}}{\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}} \text{ for vertical weir 1.13 meter high.}}$

‡ $\frac{m}{m_3} = \frac{\text{coefficient for inclined weir 0.35 meter high.}}{\text{coefficient for vertical weir 0.35 meter high.}}$

⁂ $R_2 = \frac{\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}} \text{ for inclined weir 0.35 meter high.}}{\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}} \text{ for vertical weir 0.35 meter high.}}$

The values of m and of $\left(1 - \frac{\epsilon}{h}\right)^{\frac{3}{2}}$ remain very approximately proportional, with the weir 1.13 m. (3.7 feet) high, from the inclination of 45° up-stream to that of 45° down-stream; but not for the greater inclinations of $\frac{1}{2}$ and $\frac{1}{4}$, which, however, can no longer be said to correspond to the conditions of a true weir. With the weir 0.35 m. (1.15 feet) high the two values accord rather less satisfactorily; a constant discrepancy of from one to three per cent. exists between the two series of ratios up to an inclination of 45° down-stream, beyond which the divergence becomes still more marked and reaches 8 to 9 per cent., as in the case of the higher weir.

Inasmuch as the elevation of the nappe increases as the weir becomes more and more inclined up stream, it might be asked up to what limit might the ratio $\frac{\epsilon}{h}$ be increased. If it were possible to increase the up-stream inclination of the weir until it became horizontal, we should obtain a condition analagous to the re-entering ajutage of Borda, the coefficient of discharge for which may be determined theoretically *a priori*. For this case M. Boussinesq assigns to the elevation the limit $\frac{\epsilon}{h} = 0.20$.*

At the request of this learned Academician, we have made some experiments in order to verify this limit experimentally. The crest of the weir was first armed with a horizontal plate directed up-stream, and the width of the plate was increased successively from 0.15 to 0.25 and 0.30 m. (5.9, 9.8 and 11.8 inches). Figs. 12, 13 and 15, Pl. 1.†

In order now to approximate more closely to the ideal case of a weir inclined up-stream until it becomes horizontal, we applied to the weir 1.13 m. (3.7 feet) high a curved crest-piece (Fig. 14,

* In a former article in the Comptes rendus de l'Académie des sciences, October 24, 1887, M. Boussinesq arrived at the limiting value $\frac{\epsilon}{h} = 0.22$; but further study has led him to reduce that limit to 0.20.

† These plates were held in place by four angle irons 0.018 m. (0.7 inch) in thickness, the presence of which was shown by slight ridges on the lower surface of the nappe; but this circumstance does not appear to have modified sensibly the general conditions of flow.

Pl. 1), the up-stream edge of which was horizontal, while the other edge, like the weir itself, was inclined at $\frac{3}{2}$. These experiments give the following values of $\frac{\epsilon}{h}$.

VALUES OF γ AND OF $\frac{\epsilon}{h}$ FOR WEIRS FURNISHED WITH HORIZONTAL OR CURVED PLATES PROJECTING UP-STREAM.

Figures 12 to 15, Plate I.

$\gamma = \frac{h^2}{(p+h)^2}$; h = head; p = height of weir. ϵ = upward leap of lower side of nappe.

WEIR.	HEAD.	γ	$\frac{\epsilon}{h}$
WEIRS WITH HORIZONTAL PLATE, 0.15 METER WIDE.			
	Meters.		
1.13 meter high	0.25	0.035	0.188
1.13 " "	0.30 to 0.45	0.045 to 0.08	0.176
0.35 " "	0.30	0.205	0.143
0.35 " "	0.34	0.240	0.125
0.35 " "	0.39	0.270	0.117
WEIRS WITH HORIZONTAL PLATE, 0.25 METER WIDE.			
1.13 meter high	0.40 to 0.44	0.065 to 0.075	0.170
0.93* " "	0.55 to 0.58	0.140 to 0.150	0.158
WEIR WITH HORIZONTAL PLATE, 0.30 METER WIDE.†			
0.93* metre high	0.61 to 0.65	0.16 to 0.17	0.154
WEIRS WITH CURVED PLATE.			
1.13 meter high	0.32	0.045	0.175
1.13 " "	0.35 to 0.45	0.055 to 0.08	0.169

It will be seen that the elevation $\frac{\epsilon}{h}$ of the sheet reached 0.19; but the flow over these weirs of peculiar form takes place under complicated conditions, difficult of definition, and the value of $\frac{\epsilon}{h}$ varies greatly with those conditions. It diminishes rapidly when the head h becomes considerable relatively to the height p of the weir. We have also determined the coefficient m of discharge for these weirs provided with plates.

* For heads greater than 0.55 meter it was necessary to reduce the height of the weir by 0.20 meter.

† The plate 0.30 meter wide was of wood.

SERIES NO. 31 to 34.

Experiments upon Weirs Provided with a Horizontal or Curved Plate Projecting Up-stream.

SERIES NO. 31.

VERTICAL WEIR 1.13 METER HIGH, WITH HORIZONTAL PLATE 0.15 METER WIDE.

Experiment No.	Heads Observed: on weir with plate, at head of channel. h	Heads Observed: on weir for comparison, 46 m. below. H	Ratios: $\frac{H}{h}$	Ratios: $\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	Coefficient: weir for comparison. m_2 or m_3	Coefficient: weir with plate m	Coefficient: vertical weir 1.13m. high. M	$\frac{m}{M}$
	Meters.	Meters.						
1	0.2451	0.2212	0.9025	0.8578	0.4410	0.3783	0.4259	0.888
2	0.2554	0.2298	0.8998	0.8540	0.4417	0.3772	0.4260	0.885
3	0.2650	0.2381	0.8985	0.8521	0.4424	0.3770	0.4261	0.885
4	0.2846	0.2558	0.8988	0.8525	0.4442	0.3787	0.4263	0.888
5	0.3048	0.2744	0.9003	0.8547	0.4459	0.3811	0.4267	0.893
6	0.3260	0.2930	0.8988	0.8525	0.4478	0.3817	0.4270	0.894
7	0.3445	0.3105	0 9013	0.8561	0.4495	0.3848	0.4274	0.900
8	0.3560	0.3196	0.8978	0.8511	0.4504	0.3833	0.4276	0.896
9	0.3655	0.3287	0.8993	0.8532	0.4513	0.3850	0.4278	0.900
10	0.3757	0.3376	0.8986	0 8522	0.4522	0.3854	0.4280	0.900
11	0.3853	0.3455	0.8967	0.8496	0.4529	0.3848	0.4283	0.898
12	0.4060	0.3631	0.8943	0.8461	0.4547	0.3847	0.4287	0.897
13	0.4144	0.3719	0.8974	0.8505	0.4556	0.3875	0.4289	0.903
14	0.4234	0.3783	0.8935	0.8450	0.4562	0.3855	0.4292	0.898
15	0.4338	0.3880	0.8944	0.8463	0.4573	0.3870	0.4295	0.901
16	0.4438	0.3971	0.8948	0.8469	0.4582	0.3880	0.4298	0.903
17	0.4538	0.4058	0.8942	0.8460	0.4591	0.3884	0.4300	0.903

1. EXPERIMENTS WITH WEIR FOR COMPARISON 0.50 METER (1.6 FEET) HIGH. JULY, 1888.

Temperature of water: 18° C. (64.4° Fahr.)

Weir with plate: Height, 1.133 m. (3.7 feet); Length, $l = 1.998$ m.
Weir for comparison: " 0.502 m. (1.6 feet); " $L = 1.999$ m. $\Big\} \frac{L}{l} = 1.0005.$

2. EXPERIMENTS WITH WEIR FOR COMPARISON 0.35 METER (1.15 FEET) HIGH. JULY, 1888.

Temperature of water: 18° C. (64.4° Fahr.)

Weir for comparison: Height, 0.352 meter; Length, $L = 1.998$ meter. $\frac{L}{l} = 1.$

1	0.2466	0.2197	0.8909	0.8409	0.4520	0.3801	0.4259	0.892
2	0.2765	0.2451	0.8864	0.8345	0.4557	0.3803	0.4263	0.892
3	0.2967	0.2630	0.8864	0.8345	0.4583	0.3825	0.4265	0.897
4	0.3161	0.2800	0.8858	0.8337	0.4608	0.3842	0.4269	0.900
5	0.3360	0.2966	0.8827	0.8293	0.4633	0.3842	0.4272	0.899
6	0.3476	0.3064	0.8815	0.8276	0.4648	0.3847	0.4275	0.900
7	0.3950	0.3458	0.8754	0.8191	0.4709	0.3857	0.4285	0.900

SERIES NO. 32.

VERTICAL WEIR 1.13 METER (3.7 FEET) HIGH, WITH HORIZONTAL PLATE 0.25 METER (9.8 INCHES) WIDE. APRIL, 1889.

Temperature of water: 9° C. (48.2° Fahr.)

Weir with plate: Height, 1.135 meter (3.7 feet); Length, $l = 1.996$ meter } $\frac{L}{l} = 1.$
Weir for comparison: " 0.502 " (1.97 ") " $L = 1.996$ " }

Experiment No.	Heads observed		Ratios		Coefficient			
	on weir with plate at head of channel. h	on weir for comparison, 46m. below. H	$\frac{H}{h}$	$\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{2}{3}}$	weir for comparison. m_2	weir with plate. m	corresponding weir without plate. M	$\frac{m}{M}$
	Meters.	Meters.						
1	0.3965	0.3595	0.9067	0.8634	0.4544	0.3923	0.4285	0.916
2	0.4033	0 3656	0.9065	0.8631	0.4550	0.3927	0.4287	0.916
3	0.4133	0.3744	0.9059	0.8622	0.4558	0.3930	0.4289	0.916
4	0.4243	0.3850	0.9074	0.8644	0.4570	0.3950	0.4292	0.920
5	0.4322	0.3914	0.9056	0.8618	0.4576	0.3944	0.4295	0.918
6	0.4476	0.4051	0.9050	0.8609	0.4590	0.3952	0.4299	0.919
7	0.4571	0.4132	0.9040	0.8595	0.4598	0.3952	0.4301	0.919
8	0.4679	0.4229	0.9038	0.8592	0.4608	0.3959	0.4304	0.920

SERIES NO. 33.

VERTICAL WEIR 0.35 METER (1.15 FEET) HIGH, WITH HORIZONTAL PLATE 0.15 METER (5.9 INCHES) WIDE. NOVEMBER, 1888.

Temperature of water: 9° C. (48.2° Fahr.)

Weir with plate: Height, 0.357 m. (1.17 feet); Length, $l = 1.997$ m. } $\frac{L}{l} = 0.9995.$
Weir for comparison: " 1.135 " (3.7 ") " $L = 1.996$ " }

Experiment No.	Heads observed		Ratios		Coefficient			
	on weir with plate, 46m. below head of channel.* h	on weir for comparison, at head of ch'l.* H	$\frac{H}{h}$	$\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	weir for comparison. M	weir with plate. m	vertical weir 0.35m. high. m_3	$\frac{m}{m_3}$
1	0.2818	0.2808	0 9965	0.9943	0.4263	0.4239	0.4611	0.919
2	0.2953	0.2973	1.0068	1.0097	0.4265	0.4306	0.4631	0.930
3	0.3182	0.3198	1.0050	1.0070	0.4269	0.4299	0.4666	0.921
4	0.3332	0.3381	1.0147	1.0216	0.4273	0.4365	0.4689	0.931
5	0.3540	0.3599	1.0167	1.0247	0.4277	0.4383	0.4721	0.928
6	0.3705	0.3791	1.0232	1.0345	0.4281	0.4429	0.4748	0.933
7	0.3866	0.3974	1.0279	1.0416	0.4285	0.4463	0.4773	0.935
8	0.4046	0.4186	1.0346	1.0518	0.4291	0.4513	0.4801	0.940
9	0.4239	0.4394	1.0366	1.0549	0.4297	0.4533	0.4831	0.938

* We here follow the original, which makes the positions of these weirs the reverse of those in Series Nos. 31, 32 and 34.

SERIES NO. 34.

WEIR 1.13 METER (3.7 FEET) HIGH, INCLINED $\frac{3}{2}$ UP-STREAM, AND FURNISHED WITH A CURVED PLATE. JULY, 1888.

Temperature of water: 17.5° C. (63.5° Fahr.)
Weir with curved plate: Height, 1.142 meter; Length, $l = 1.998$ meter } $\frac{L}{l} = 1.0005$.
Weir for comparison: " 0.502 " " $L = 1.999$ " }

Experiment No.	Heads observed		Ratios		Coefficient			$\frac{m}{M}$
	on weir with plate, at head of channel. h	on weir for comparison, 46m. (152 ft.) below. H	$\frac{H}{h}$	$\frac{L}{l}\left(\frac{H}{h}\right)^{\frac{3}{2}}$	weir for comparison. m_2	weir with plate. m	vertical weir 1.13m. high. M	
	Meters.	Meters.						
1	0.3209	0.2874	0.8956	0.8480	0.4472	0.3792	0.4269	0.888
2	0.3391	0.3042	0.8971	0.8501	0.4488	0.3815	0.4273	0.893
3	0.3596	0.3210	0.8927	0.8439	0.4505	0.3802	0.4277	0.889
4	0.3800	0.3389	0.8918	0.8426	0.4523	0.3811	0.4281	0.890
5	0.3981	0.3556	0.8932	0.8445	0.4540	0.3834	0.4286	0.895
6	0.4183	0.3726	0.8907	0.8410	0.4557	0.3832	0.4290	0.893
7	0.4345	0.3865	0.8895	0.8393	0.4571	0.3836	0.4295	0.893
8	0.4500	0.3990	0.8867	0.8354	0.4584	0.3829	0.4299	0.891

The results of these four series of experiments may be condensed as follows:

Heads.	Values of $\frac{m}{M}$. Weirs 1.13m. (3.7 Ft.) High.			Values of $\frac{m}{m_3}$
	With horizontal plate, 0.15m. wide. Series No. 31.	With horizontal plate, 0.25m. wide. Series No. 32.	With curved plate. Series No. 34.	Weir 0.35m. (1.15 ft.) high, with horizontal plate, 0.15m. wide. Series No. 33.
Meters.				
0.25 to 0.35	0.893	—	0.891	0.925
0.35 to 0.45	0.900	0.918	0.892	0.935

The smallest values of $\frac{m}{M}$ were obtained with the curved plate, the substitution of a plate 0.25 m. (9.8 inches) wide for that of 0.15 m. (5.9 inches) having no effect upon the coefficient except to increase rather than diminish it. The weir 0.35 m. (1.15 feet) high gives results sensibly greater.

We will now compare, as we did for the inclined weirs, the

ratios of the corresponding values of $\frac{\epsilon}{h}$. We have taken twelve complete profiles of the sheet on the weir 1.13 m. (3.7 feet) high, as follows:*

Series No.	31.—5	profiles,	heads from	0.25 to 0.45 m. (9.8	to 17.7 ins.).
"	32.—2	"	"	0 40 to 0.45 m. (15.75	").
"	33.—5	"	"	0.30 to 0.45 m. (11.8	").

With the weir 0.35 m. (1.15 feet) high (Series No. 34), we deemed it sufficient to observe, for three heads comprised between 0.30 and 0.40 m. (11.8 and 15.75 inches), that part of the profile in the neighborhood of the summit of the curve.

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* See, at the end of this paper, the tables of co-ordinates obtained by direct observation.

Series.	Weir 1.13 meter (3.7 Feet) High.					Weir 0.35 Meter (1.15 Feet) High.				
	$\frac{\epsilon}{h}$	$\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}}$	Ratio of Coefficients of weir with plate and typical weir $\frac{m}{M}$	Corresponding ratios of $\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}}$	Differences.	$\frac{\epsilon}{h}$	$\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}}$	Ratio of Coefficients of weir with plate and typical weir $\frac{m}{m_3}$	Corresponding ratios of $\left(1-\frac{\epsilon}{h}\right)^{\frac{3}{2}}$	Differences.
CREST WITH HORIZONTAL PLATE, 0.15 METER (5.9 INCHES) WIDE.										
Series No. 31 — Profile No. 1. Head 0.25m.	0.188	0.732	0.888	0.875	—0.013					
Series No. 31 — Profiles Nos. 2 to 5. Head 0.30 to 0.45m.	0.176	0.748	0.898	0.894	—0.004					
Series No. 34 — Profile No. 1. Head 0.30m.						0.143	0.793	0.923	0.927	+0.004
Series No. 34 — " No. 2. " 0.34m.						0.125	0.818	0.930	0.957	+0.027
Series No. 34 — " No. 3. " 0.39m.						0.117	0.830	0.936	0.971	+0.035
CREST WITH HORIZONTAL PLATE, 0.25 METER (9.8 INCHES) WIDE.										
Series No. 32 — Profiles No. 1 and 2. Heads 0.40 to 0.44m.	0.170	0.756	0.918	0.903	—0.015					
CREST WITH CURVED PLATE.										
Series No. 33 — Profile No. 1. Head 0.32m.	0.175	0.749	0.890	0.895	+0.005					
Series No. 33 — Profiles Nos. 2 to 5. Head 0.35 to 0.45m.	0.169	0.758	0.892	0.906	+0.014					
CREST IN THIN PARTITION.										
Typical weir	0.112	0.837	1 000	1.000	0	0.099	0.855	1 000	1.000	0

The proportionality between m and $\left(1 - \frac{\epsilon}{h}\right)^{\frac{3}{2}}$ is here less satisfactorily maintained than in the case of the inclined weirs; thus the values of m obtained from Series Nos. 32 and 33 differ about 3 per cent., while that of $\frac{\epsilon}{h}$ remains sensibly constant. On the weir 0.35 m. (1.15 feet) high the discrepancy is more important, $\frac{\epsilon}{h}$ varying greatly with the head, whereas, on the contrary, the ratio $\frac{m}{m_3}$ is nearly constant.

Let us now turn to the study of the upper curve. The most important point in this investigation is the determinatien of the ratios $\frac{e}{h}$ and $\frac{\eta}{h}$, where e is the thickness AE^* of the nappe above the crest A, and η that (SF) of the nappe above the summit S of the lower curve. These ratios vary considerably. Their values are given in the table below, which gives also the lengths $\frac{c}{h}$ of the horizontal chord AB of the lower curve.

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* See figure p. 232, Vol. IX, No. 3.

Series.			Extreme values of γ	Summit of lower curve.		Ordinates of upper curve.		Thickness of nappe over summit of lower curve.	L'ngth of chord.
				abscissæ	ordinates	over the crest.	over summit of lower curve.		
				$\frac{x}{h}$	$\frac{\varepsilon}{h}$	$\frac{e}{h}$		$\frac{\eta}{h}$	$\frac{c}{h}$
WEIRS FURNISHED WITH HORIZONTAL PLATES TO INCREASE THE CONTRACTION AT THE CREST.									
Plate 0.15 m. (5.9 ins.) wide.	Weir 1.13 m. high (3.7 ft.) Series No. 31.	Head 0.25 m.	0.035	0.25	0.188	0.871	0.800	0.618	0.77
		Heads 0.30 to 0.45 m.	0.045–0.08		0.176				
	Weir 0.35 m. high (1.15 ft.) Series No. 33.	Head 0.30 m.	0.205	0.25	0.143	0.865	. . . . .		
		" 0.34 m.	0.24		0.125				
		" 0.39 m.	0.27		0.117				
Curved plate.	Weir 1.13 m. high Series 34.	Head 0.32 m.	0.045	0.25	0.175	0.869	0.796	0.624	0.76
		Heads 0.35 to 0.45 m.	0.055–0.08		0.169				
Plate 0.25 m. (9.8 ins.) wide.	Weir 1.13 m. high Series No. 32.	Heads 0.40 to 0.44 m.	0.065–0.075	0.25	0.170	0.873	0.801	0.631	0.76
INCLINED WEIRS.									
Inclination $\frac{1}{4}$ up-stream.	Weir 1.13 m. high Series No. 11.	Heads 0.30 to 0.45 m.	0.045–0.08	0.25	0.159	0.868	0.796	0.637	0.75
	Weir 0.35 m. high Series No. 23.	Head 0.20 m.	0.13		0.128	0.867	0.800	0.676	0.67
		Heads 0.30 to 0.39 m.	0.205–0.27		0.120				
Inclination $\frac{3}{2}$ up stream.	Weir 1.13 m. high Series No. 12.	Heads 0.20 to 0.45 m.	0.025–0.08	0.25	0.150	0.864	0.792	0.642	0.74
	Weir 0.35 m. high Series No. 24.	" 0.20 to 0.26 m.	0.13 –0.175		0.125	0.862*	. . . . .		
		" 0.31 to 0.37 m.	0.22 –0.26		0.117				

$\frac{3}{1}$ up-stream	Weir 1.13m. high, Series No. 13.	Heads 0.20 to 0.44m.	0.025–0.08	0.25	0.136	0.860	0.788	0.652	0.72
	Weir 0.35m. high, Series No. 25	" 0.18 to 0.25m.	0.11–0.17		0.119	0.858			
		" 0.33 to 0.40m.	0.23–0.28		0.108				
Vertical	Weir 1.13m. high, Series Nos. 1, 2.	Heads 0.15 to 0.45m.	0.015–0.08	0.25	0.112	0.851	0.780	0.668	0.68
	Weir 0.35m. high, Series Nos. 8, 9.	" 0.12 to 0.30m.	0.065–0.21		0.100	0.857	0.787	0.688	0.65
		" 0.35 to 0.45m.	0.25–0.315		0.097				
$\frac{3}{1}$ down-stream	Weir 1.13m. high, Series No. 14.	Heads 0.20 to 0.45m.	0.025–0.08	0.23	0.089	0.832	0.767	0.678	0.61
	Weir 0.35m. high, Series No. 26.	" 0.18 to 0.25m.	0.11–0.17		0.084	0.844			
		" 0.32 to 0.39m.	0.22–0.27		0.083	0.853			
$\frac{3}{2}$ down-stream	Weir 1.13m. high, Series No. 15.	Heads 0.20 to 0.44m.	0.025–0.08	0.21	0.061	0.811	0.750	0.689	0.53
	Weir 0.35m. high, Series No. 27.	" 0.19 to 0.27m.	0.12–0.18		0.058	0.816			
		" 0.32 to 0.39m.	0.23–0.28		0.058	0.829			
$\frac{1}{1}$ down-stream	Weir 1.13m. high, Series No 16.	Heads 0.20 to 0.44m.	0.025–0.075	0.17	0.041	0.789	0.740	0.699	0.43
	Weir 0.35m. high, Series No. 28.	" 0.20 to 0.30m.	0.13–0.215		0.041	0.807	0.766	0.725	0.42
		" 0.39m.	0.275		0.041	0.837	0.788	0.747	0.43
$\frac{1}{2}$ down-stream	Weir 1.13m. high, Series No. 17.	Heads 0.20 to 0.40m.	0.025–0.07	0.11	0.012	0.732	0.698	0.686	0.23
	Weir 0.35m. high, Series No. 29.	" 0.20 to 0.30m	0.135–0.21		0.018	0.751	0.715	0.697	0.26
		Head 0.39m.	0.275		0.017	0.775	0.742	0.725	0.27
$\frac{1}{4}$ down-stream	Weir 1.13m. high, Series No. 18.	Heads 0.21 to 0.40m.	0.025–0.07	0.05	0.003	0.660	0.645	0.642	0.10
	Weir 0.35m. high, Series No. 30.	" 0.20 to 0.30m.	0.135–0.215		0.004	0.671	0.655	0.651	0.10
		Head 0.40m.	0.29		0.004	0.697	0.683	0.679	0.11

* The value corresponding to profile No. 4 appeared to be erroneous, and it is therefore not included.

An inspection of this table develops the following laws:

(1) The thickness $\frac{e}{h}$ of the nappe over the crest diminishes as the weir is inclined down-stream; this diminution, barely perceptible so long as the weir is inclined up-stream, becomes much greater when we pass to weirs inclined down-stream.

(2) For a given inclination $\frac{e}{h}$ increases with the head h, or rather with the ratio $\frac{h}{p}$ or γ, as is shown by the experiments with the weir 0.35 m. (1.15 feet) high.

(3) The thickness $\frac{\eta}{h}$ of the *nappe*, measured over the summit of the lower curve, increases from the greatest observed inclinations up-stream to that of $\frac{1}{1}$ (or 45°) down-stream, beyond which it diminishes.

(4) The length $\frac{c}{h}$ of the chord decreases as $\frac{\epsilon}{h}$ decreases.

It may be well to observe, moreover, that for weirs inclined *up*-stream, the inclination, although it modifies considerably the value of $\frac{\epsilon}{h}$, has but little effect upon that of $\frac{e}{h}$, which does not vary as much as 0.02 as we pass from the vertical weir to an up-stream inclination of 45°. This is no longer the case when the weir inclines *down*-stream; $\frac{e}{h}$ then diminishes rapidly and the curvature of the surface becomes elongated as the inclination increases (Fig. 2, Pl. 3).*

The complete profiles of the nappes, for the nine inclinations experimented upon with the weir 1.13 m. (3.7 feet) high, are grouped in Fig. 1, Pl. 3. That figure shows that, as the weir is inclined more and more down-stream, the upper surface in the neighborhood of the crest of the weir is lowered nearly parallel with itself, and thus does not participate in the change of form of the under surface.

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* Owing to this elongation, the heads were measured at a point 10 m. (33 feet) up-stream for the weir 1.13 m. (3.7 feet) high, inclined at $\frac{1}{2}$ and $\frac{1}{4}$ (Series Nos. 17 and 18).

We have already shown that from an inclination of 45° up-stream to that of 45° down-stream, the coefficient m of discharge varies nearly in proportion to $\left(1 - \frac{\epsilon}{h}\right)^{\frac{3}{2}}$, as indicated by the formula of M. Boussinesq. Let us now compare the absolute values of these coefficients with that assigned to them by this formula. To effect this comparison we must first remark that the formula relates to the theoretical case where the velocity of approach above the weir is supposed to be zero. We have already seen that, in order to take account of that velocity, u, the coefficient μ for the case where there is no velocity of approach, must be multiplied by $1 + \frac{3}{2} a \frac{u^2}{2gh}$, or, which amounts to nearly the same thing, by $1 + K\left(\frac{h}{h+p}\right)^2$. The coefficients a and K are variables, and we have assumed for them, as mean values to be employed in practice, $a = \frac{5}{3}$, $K = 0.55$. M. Boussinesq, approaching the question from a theoretical point of view, has arrived at an expression of the same form, and has shown that the coefficients a and K vary, in fact, with several different elements, and notably with $\frac{\epsilon}{h}$ and $\frac{h}{p}$.* He has been led to adopt, for a vertical weir, $K = 0.42$.

In the particular case with which we are concerned, the factor $K\gamma$ represents only a small fraction of m, and it therefore matters little whether we take $K = 0.42$ or $K = 0.55$, especially as this coefficient is no doubt variable in our inclined weirs. We shall, therefore, put simply $K = 0.42$, although that value may be rather too small, and the formula to be applied to the calculation of the coefficients will then be:

$$m = 0.5216 \left(1 - \frac{\epsilon}{h}\right)^{\frac{3}{2}} (1 + 0.42\,\gamma).$$

The mean value of the factor $1 + 0.42\gamma$ being

For Heads from	$1 + 0.42\gamma$
0.10 m. to 0.15 m. (3.94 to 5.90 ins.)	1.004
0.15 m. to 0.25 m. (5.90 to 9.84 ins.)	1.010
0.25 m. to 0.35 m. (9.84 to 13.8 ins.)	1.018
0.35 m. to 0.45 m. (13.8 to 17.7 ins.)	1.029

we obtain the following series of coefficients:

* Comptes rendus de l'Académie des sciences, September 17 and 24, 1888.

VALUES OF **m** (COEFFICIENT OF DISCHARGE), AS AFFECTED BY INCLINATION OF WEIR.

		Up-stream Inclinations.			Ver-tical	Down-stream Inclinations.				
		1/1	3/2	3/1		3/1	3/2	1/1	1/2	1/4
Values of $\frac{\epsilon}{h}$		0.159	0.150	0.136	0.112	0.089	0.061	0.041	0.012	0.003
Observed values of m for weir 1.13m. (3.7 feet) high.	Heads from 0.10 to 0.15m.	. .	. .	. .	0.4307	0.4488	0.4668	0.4777	0.4896	0.4692
	0.15 to 0.25m.	. .	0.3989	0.4066	0.4266	0.4456	0.4636	0.4762	0.4844	0.4719
	0.25 to 0.35m.	0.3941	0.3986	0.4098	0.4266	0.4469	0.4650	0.4768	0.4850	0.4728
	0.35 to 0.45m.	0.3976	0.4005	0.4136	0.4286	0.4488	0.4656	0.4775	0.4883	0.4744
Values of m by the formula.	Heads from 0.10 to 0.15m.	. .	. .	. .	0.4383	0.4556	0.4766	0.4918	0.5143	0.5211
	0.15 to 0.25m.	. .	0.4130	0.4230	0.4409	0.4583	0.4794	0.4947	0.5173	0.5242
	0.25 to 0.35m.	0.4094	0.4163	0.4264	0.4444	0.4620	0.4832	0.4986	0.5214	0.5283
	0.35 to 0.45m.	0.4138	0.4208	0.4310	0.4492	0.4669	0.4884	0.5040	0.5270	0.5340
Ratios between calculated and experimental values of m.	Heads from 0.10 to 0.15m.	. .	. .	. .	1.018	1.015	1.021	1.030	1.050	1.111
	0.15 to 0.25m.	. .	1.035	1.040	1.034	1.029	1.034	1.039	1.068	1.111
	0.25 to 0.35m	1.039	1.044	1.041	1.042	1.034	1.039	1.045	1.075	1.117
	0.35 to 0.45m.	1.041	1.051	1.042	1.048	1.040	1.049	1.055	1.079	1.126

The discrepancy between the formula and the experiments, scarcely perceptible under small heads, increases quite rapidly with h and reaches about 5 per cent. when $h = 0.45$ m. (17.7 inches). Inasmuch, however, as the formula takes no account of the retarding effect of friction, which must necessarily reduce the theoretical discharge, and since the effect of friction no doubt increases with the velocity of approach, it was foreseen that the discrepancy due to this omission in the formula would increase progressively with the discharge over the weir. An attentive observation of the phenomenon shows this explanation to be very plausible.

When the head is small, the velocity in the stream above the weir is scarcely perceptible, and the nappe, perfectly smooth and transparent, appears almost motionless, or at least presents very feeble oscillations. But as the head increases, the velocity

becomes more apparent in the channel up-stream, and the whirling motions which accompany it begin to extend to the nappe itself, the surface of which, now more agitated, becomes covered with streaks which increase in prominence as the elevation $\frac{\epsilon}{h}$ becomes more considerable. With weirs inclined up-stream (in which the eddies are especially noticeable),* these streaks occasionally form very prominent and very slowly moving ridges. On the other hand, a down-stream inclination reduces these movements and renders the profile of the nappe more regular. When the head h becomes considerable, relatively to the height p of the weir, the whole flowing mass appears to be animated by a very pronounced undulatory movement; the up-stream surface oscillates incessantly, and the exact determination of its elevation would be most difficult without the aid of a lateral chamber sheltered from these semi-periodic oscillations, the amplitude of which diminishes also when the weir is inclined down-stream.

The conditions of flow are thus modified as the head varies, owing to the progressive development of eddies in the liquid vein. We thus account for the fact that the coefficient m of the well-known formula decreases at first (as we have shown in our gauging experiments), when the head is gradually increased above 0.05 m. (2 inches). This decrease stops and is reversed when the importance of the factor $K\gamma$, corresponding to the action of the velocity of approach, becomes predominant. This explains also why the formula of M. Boussinesq, giving a first

*This agitation of the nappe renders the exact determination of its profile more difficult than with vertical weirs or those inclined down-stream. We observe, furthermore, after the up-stream inclination reaches $\frac{3}{2}$, a very curious phenomenon: eddies form from time to time near the ends of the nappe, below the crest of the weir, rising gradually until they reach the level of the crest. After passing it they suddenly become elongated downward and appear like a long silver serpent above the weir. They remain there for a few moments and then disappear instantaneously, leaving a trace composed of small particles of silt carried up from the bottom of the channel. The eddies rotate in a sense just the opposite of what might be expected; that is to say, an observer viewing the weir from a point up-stream would see the eddies produced on the right-hand side turn from right to left, and those produced on the left-hand side turn from left to right.

approximation to the coefficient and neglecting friction, accords with the experimental values for small heads, but gives too high coefficients when, owing to the increase of the discharge, we come to increasing resistances, of which it takes no account. M. Boussinesq's formula must also, for another reason, assign to the coefficient a value somewhat too high; for it assumes that there exists in the nappe a contracted section where the liquid filaments are parallel, whereas an examination of the profiles shows that the upper and lower surfaces of the nappe are not parallel, but convergent. The discharge calculated under the hypothesis of parallelism must therefore be somewhat exaggerated.

Coefficients of Reduction to be Employed in Practice.

Inclined weirs seldom occur in practice. They are, however, sometimes met with (as in sluices, gates in movable weirs, etc.), and it will be well to seek for the coefficient to be employed in each particular case. The measurement of the elevation $\frac{\epsilon}{h}$ being too delicate an operation to be admissible in practice, we must be satisfied with coefficients of correction, more or less approximate, and decide by what ratio or modulus the coefficient for the vertical weir must be multiplied in order to adapt it to a given inclination. This modulus varies considerably when the ratio $\frac{h}{p}$ approaches unity; but omitting such cases (which should always be avoided), we may adopt the following series of coefficients:

EFFECT OF INCLINATION OF WEIR UPON COEFFICIENT OF DISCHARGE **m** AND UPON THE THICKNESS OF THE NAPPE OVER THE CREST.

INCLINATION.	MULTIPLY **m** FOR THE VERTICAL WEIR BY	$\frac{\epsilon^*}{h}$
Up-stream $\frac{1}{1}$	0.93	0.87
Up-stream $\frac{3}{2}$	0.94	0.865
Up-stream $\frac{3}{1}$	0.96†	0.86
Vertical	1.00	0.855
Down-stream $\frac{3}{1}$	1.04	0.84
Down-stream $\frac{3}{2}$	1.07	0.82
Down-stream $\frac{1}{1}$	1.10	0.80
Down-stream $\frac{1}{2}$	1.12	0.75
Down-stream $\frac{1}{4}$	1.09	0.67

* e = thickness of nappe over crest; h = head.

† M. Boileau, experimenting with a weir 0.458 meter (1.5 feet) high, inclined $\frac{3}{1}$, found 0.973 as the value of this modulus. (*Traité de la mesure des eaux courantes*, pp. 146–148.)

As already observed, the inclinations $\frac{1}{2}$ and $\frac{1}{4}$ do not properly come under the head of weir-flow. The stream approaching the weir, instead of contracting freely in passing over a triangular prism of eddying water, is guided by the inclined plane of the weir, with which it is in immediate contact. This modification of the phenomenon appears very clearly in the several series of ratios which we have calculated; as also in the elongation of the upper curve of the nappe, the junction of which with the up-stream level surface no longer takes place, as in the other weirs, at a distance from the crest equal to only four or five times the head h. Hence, while the results which we have obtained with these low inclinations may prove to be of use in certain special cases, they must not be regarded as connected directly with the theory of the weir.

XVIII.

THE INFLUENCE OF RAINFALL ON COMMERCIAL DEVELOPMENT: A STUDY OF THE ARID REGION.

By Jacques W. Redway, Active Member of the Club.

Read April 2, 1892.

Forty years ago there was one feature on maps of the United States that invariably demanded the respectful attention of any one who might unfortunately seek information concerning the topography and drainage of our possessions west of the Mississippi River. This impressive feature was a vast area of territory, roughly elliptical in shape and severely definite in outline, bearing on its face the portentous name, "Great American Desert."

In time, as settlement and exploration pushed westward, the boundaries of this area, little by little, were contracted, until they finally disappeared, and the name itself was transferred to a small and indefinite territory lying west and south of Great Salt Lake—the dry bed of a former inland sea, which, at a period not greatly remote, poured its surplus waters into a tributary of the Columbia River. Thereupon it became the custom to smile at the ignorance of our cartographers whenever any allusion to our desert possessions was made, and we triumphantly pointed to the statistics of population and produce in refutation of such an absurdity. At the same time we gave with a free hand from our treasury of public lands to whomsoever that asked. Among the recipients of public bounty were, it is needless to say, railway corporations, cattle-syndicates and land-speculating trusts. The rest was left to the bona-fide settler, with an implied understanding that he must not complain if a railway company or a land trust swooped down upon his home and holdings, after he had improved the land and made it productive. It is almost superfluous to add that the cultivable prairies and the river-bottom lands were acquired mainly by the speculators and corporations. The remainder was the property of the homestead and the pre-emptor, and it is concerning this remainder that I wish to present a few facts.

It may be considered a piece of impertinence to intimate that neither the average newspaper writer nor the average reader does not fully comprehend the somewhat indefinite term "desert." I am inclined to believe, however, that he does not. Almost always we associate the word with a vast expanse of sand. Even the critical German geographer habitually speaks of it as a sand-waste (*sand-wüste*), and the term "sanding" is technically applied to the stipple-marks that on our maps conventionally represent desert areas. True sand, however, a form of silica, is the oxide of the non-metal silicon, and is usually a product of sea-shores. Excepting the external varnish of silica, which protects and strengthens the stalks of certain endogens, this element plays no part in biological processes or in plant economy in general. Mixed with clayey soils, it mechanically renders them more porous, and by increasing their capillarity, gives to them a greater power to hold as well as to absorb moisture. This element is not an essential, however, and a soil of pure sand is absolutely sterile.

Now if there is anything scarce in desert regions it is true sand; water is abundant in comparison. That there are vast extents of finely-divided pulverulent soil that shifts and drifts with the winds, is true. Except in rare instances, however, it is not sand. The quarternary, detrital deposit covering the Colorado Desert of Southern California is an example in question. This substance passes casually for sand, and, as a matter of detail, it makes a most excellent mortar, both for masonry and interior finish. It contains a small percentage of silica, but a close examination shows it to be composed of finely-divided felspathic rock—the disintegrations of granite, syenite, and actinolite—extraordinarily rich in all the elements, water excepted, for the fullest development of plant life.

To a greater or less extent the same is practically the case of most desert areas. So far as physiographic condition is concerned, the soil of a desert may be of almost any character, detrital or sedentary, shingly or pulverulent, compact or drifting, basic, acid, or saline, in chemical structure. Moreover, topographically and physiographically, the surface may be level, undulating, or mountainous; the climate may be hot or

cold, equable or extreme. There is one essential mineral element wanting, and until this is supplied, a desert will be a desert, no matter how rich its soil. This essential is water, and its presence or absence makes practically the only distinction between fertile and barren lands. That there are localities, the soil of which is destitute of nutritive minerals, or which contains substances fatal to the existence of plant-life, is true; but such areas are inconsiderable in size, and they are impartially distributed among both rainless and rainy regions.

Deserts, therefore, may be defined as regions deficient in the amount of moisture necessary to support plant life. Practically, one may make a more conventional distinction, and regard them as regions so dry that ordinary food-plants will not mature there. The belief that the soil of deserts is innutritious, has become almost traditional. Yet, as a rule, the contrary is true; it is rich, because few, if any, of its nutritious principles have been exhausted. The truth of this statement is emphasized when one recalls the few artificial oases in the Colorado and Mojave deserts. The former is a broad expanse of white, felspathic detritus, mercilessly pelted by sand-blasts and writhing under a sun so scorching that even the few species of cactus wither and turn yellow; yet at Los Palmas, a small tract watered by an almost forgotten spring, yields such a profusion of flowers and tropical fruit, that one might almost imagine it the Vale of Paradise planted beyond the reach of profane defilement, and guarded by fierce simoons.

In view, therefore, of the fact that a desert owes its characteristic conditions to a lack of water, and bearing in mind also that the rainfall of an area as large as the United States may vary from *nil* to one hundred inches or more, one might expect to find almost every possible degree of productivity; and this is the case. Plant-life is far more sensitive to the vagaries of rainfall than one would naturally suspect. A difference of one or two inches in amount, or the slightest disturbance in the distribution of precipitation, may decide whether a given species will thrive or perish in a certain region. Indeed, so extremely sensitive are some well-known species of food-plants, that the distribution of precipitation unchanged, a deficiency of one inch in amount

over the region cultivated would cause a measurable disturbance in the industries of that region. That is, if ten inches in amount, or a monthly distribution, is essential to perpetuate a species of grass, it will thrive and extend its geographical limits when the annual rainfall is eleven inches; it will perish and disappear if the precipitation is reduced to nine inches, or if there be yearly a period of drought exceeding one month.

In the United States we find not only an annual precipitation, varying from practically nothing to one hundred inches, but in the matter of distribution, also, there is every variety, from a cloud-burst once in two or three years, to an almost steady downpour during ten out of every twelve months, and occasional showers during the remaining two.

East of the Mississippi River there is practically no area in which, so far as moisture is concerned, grass and the cereals cannot be profitably and profusely grown. In no part is the rainfall less than thirty inches per year, and the average is nearer forty inches. If there be any cultivable part of this region, therefore, in which grass- and grain-growing is unprofitable, it is because of the high value of the land, or else its inaccessibility to a market. A high value of land is, of course, an effectual bar to grain-growing; but inasmuch as land at $1,000 per acre will commonly yield a much greater income from other products than land at $30 per acre sowed to wheat or corn, there is little or no actual loss of productivity. The Mississippi Valley is one of the most fertile regions in the world, and if we consider its size, it is capable of producing a more valuable harvest than any other river valley on the face of the earth. And if its grain-producing power is not enough, there are the almost inexhaustible stores of coal and iron. So far as natural resources are concerned, there is no reason why this region should not become the greatest empire under the sun, for there is no other of equal size capable of supporting so large a population.

Beyond the Missouri the rainfall lessens considerably. The northern part of the Pacific slope excepted, no part of this area receives more than thirty inches of rain, and in the greater part —aggregating nearly one-fourth the area of the whole country— the annual precipitation is less than fifteen inches. For con-

venience we will divide this extent of area into three regions: the "Plains," the Colorado Plateau, and the Great Basin. There must also be included the inaccessible and therefore uncultivable mountain slopes; in some instances snow-covered, in others denuded of soil.

By far the most fruitful area of the three is the region commonly known as the "Plains." From the Missouri River westward it rises imperceptibly to a plateau, varying from 3,000 to 6,000 feet in elevation. The eastern part receives a generous supply of rain, and as far west as the 96th meridian it is all that can be desired in point of fertility. West of this meridian farming is carried on mainly in the river-bottom lands. Grain-farming on the sedentary or "bluff" soil is too uncertain in its results, and this part is given up to stock-raising. West of the 99th meridian there is but little land of any kind that may be called productive. Even along the small streams about the only crops that are produced are confined to small patches of barley or of corn. Probably ninety-five per cent. of this area is used directly or indirectly for stock-raising, and in the last twenty years it has been so thoroughly overstocked that at present, instead of the traditional two head of cattle that an acre of land is supposed to support, an average of at least four or five acres is necessary to each head. Not an acre has ever been seeded or in any way cultivated; on the contrary, its surface has been so thoroughly tamped and packed by the hoofs of millions of cattle, that the productive power of the soil is reduced to its minimum value. It is cheaper to rob the United States of the nutritive elements of the soil than to buy the land. In the opinion of the stockmen, it is more economical to starve a herd once every seven or eight years, than to feed a smaller herd a part of every year. In other words, the average grazier is content to have the one golden egg, and bequeath to posterity the carcass of the goose. The fact that the food-producing power of the plains is growing less with each succeeding year, has not been emphasized. Not only is the percentage of growing grass reduced each succeeding year, because of the lessened amount of seed falling upon it, but the everlasting impact of hoofs has so packed the soil that its power to receive and hold the small amount of water is also

greatly lessened. The water, therefore, instead of penetrating the ground, is drained off at the surface; so the soil is not only becoming poorer, but drier. Its grass-producing power can be increased only by plowing and seeding, and, under the present laws, this step is out of the question. Grass once weakened in vitality, if not destroyed by the cattle, becomes the prey of noxious weeds, and the latter ultimately take its place. What is every one's business in this case is so manifestly no one's business that such a thing is not to be considered.

The Colorado Plateau is bounded mainly by the Uinta and Wasatch Mountains. The upper part of the river-basin is in a fertile and well-watered region. It comprises within its area a large amount of cultivable land and some of the best stock ranges in the country. The greater part of the drainage basin, however, consists of a succession of sandstone mesas—the bottoms of old lake-basins, that in past geological times were upheaved and synchronously desiccated. Through this area—somewhat more than 250,000 square miles in extent—the river and its tributaries flow in cañons, varying from a few hundred to more than six thousand feet deep. The streams, therefore, are practically underground streams, and so far as supplying water for purposes of irrigation, they are of little or no actual use.

The plateaus, though characterized by a monotony of structural detail, are vastly different in climate and physiographic aspect. Shivwits Plateau, for instance, the lowest in altitude, is generally barren and desolate. The edges are frayed and notched with gulches and miniature cañons, which carry water only when some straggling rain-cloud discharges its contents on the mesa, in the form of a cloud-burst. Springs are found here and there, however, and around the vicinity of each are clustered the wickiups of the squalid Shivwits Indians, who manage to exist on the few acres of corn they cultivate. Uinkaret Plateau, one of higher altitude, is more habitable. It receives a fairly generous rainfall, and, in consequence, there is a considerable area of good grazing land, with here and there a stream flood-plain of a few square miles in extent. Kaibab Plateau is the highest of the mesas. Owing to its altitude it is covered with deep snows during the winter months, and as it possesses a deep and nutritious

soil, there is an abundance of grass and timber. Owing to the topography it is not generally well suited for cultivation, but no better region can be found for summer grazing. These three mesas are fair types of the surface of the Colorado plateaus. The lowest, "sandy" and alkaline in character, are worthless for the cultivation of crops, unless the latter be of lizards and rattlesnakes. The midlands are moderately well watered, but the cultivable lands are confined to the river valleys. The highlands are cold but productive. The lower course of the Colorado River —and of several of its tributaries as well—lies practically in a desert region that possesses no drainage to the ocean. The rainfall is scant, rarely exceeding an inch or two a year, and in many places consisting of nothing more than an occasional cloudburst.

The Gréat Basin proper is a triangular-shaped area, about 225,000 square miles in extent. The northern part borders on the drainage area of Columbia and Klamath rivers. It receives sufficient rain to insure a fair yield of grain on such land as is adapted to grain-growing; but here, as in other parts of the western highlands, grain-growing must be confined to the river flood-plains. The central part of the basin is traversed by parallel ridges, the upturned edges of immense, faulted blocks, having gentle eastern and abrupt western slopes. The base of the plateau, or more correctly speaking, the floor of the basin on which these ridges rest, is from 3,000 to 5,000 feet above sea-level in its greater extent. The ridges themselves have an altitude varying from 7,000 to 11,000 feet, and are therefore capable of wringing more or less moisture from the few clouds that pass the crests of the Sierra Nevada Mountains.

The northern part of the Great Basin has a rainfall sufficient, by the aid of irrigation, to make productive a few thousand square miles of land. The central part contains but little grazing and less cultivable land. The higher slopes of the ridges are grass-covered, and at their bases there are a few ephemeral streams whose flood-plains may possibly afford each a small acreage of barley-fields. The only streams of any size are Humboldt, with its tributary Reese, and Carson River. In their upper courses these streams are mountain torrents. In their

lower parts, however, they carry but little water, and in very hot weather disappear altogether. A few square miles, suitable for garden or barley ranches, is the extent of the cultivable land in their basins.

The lowest and southern part of the Great Basin is irreclaimable and practically uninhabitable. Excepting the crests of the granitic ridges, there are but few parts of this region more than 1,000 or 1,500 feet above sea-level, while more than 2,000 square miles are below it. Along the western edge there are here and there a few acres of land that may be made productive by irrigation, but even these spots, rare as they are, are seldom utilized. Death Valley and the Sink of the San Felipe—the latter now better known as Salton Lake—are situated in this part of the Great Basin. The whole region is typically a desert. Cacti and yuccas are about the only forms of vegetable life, and in much of the area these are dead, and their spiked, thorny stalks and trunks are bleached to whiteness under a scorching sun whose direct rays register 130° to 145° on the thermometer. So intense is the heat in this region that evaporation from a body of water of considerable depth exceeds 100 inches per year; in shallow pools it is nearer two-thirds of an inch a day. The Sink of San Felipe River is scarcely 600 square miles in area, yet the whole flood of the Colorado River is insufficient to fill it to the level of the sea.

The foregoing paragraphs give a brief description of the arid lands of the United States. In round numbers this region has an area of 1,340,000 square miles, or upwards of 900,000,000 acres. This does not include all the land where crops must be irrigated; there is a belt one hundred miles in width or more, lying on both sides of the 98th meridian, in which crops may mature finely one season, and, for want of water, perish the next. But leaving this area out, we must open our eyes to the fact that one-third of the territory of the United States consists of land that cannot yield food-crops without artificial aid. Of this vast area Professor Powell estimates about 500,000,000 acres would be productive were there sufficient rainfall. The remainder consists of rock and shingly surfaces, and of slopes so rugged that their cultivation would be out of the question.

Now, experience has shown that an acre-foot of water—that is, the equivalent of a rainfall of twelve inches—if applied to the ground judiciously, is sufficient to insure a fair grain crop. We must bear in mind, however, that this estimate is an average rather than an actual value. In stiff, impervious soils, especially if there be considerable slope, twice that quantity of water might not suffice, while in the loamy soil of San Fernando Valley, in California, six inches of rain, falling opportunely, will insure a fair yield of grain. Taking all the factors into consideration, however, the surveys of Professor Powell demonstrate that about 100,000,000 acres of the now unproductive lands of the United States may be reclaimed—an area about four times that of Pennsylvania, or nearly equal to that of Ohio, Indiana, Illinois and Iowa combined.

Now, the reclamation of these lands, which at present are practically deserts, must depend on irrigation; but the manner in which the water must be obtained may be one or more of three ways: storage of surplus waters, artesian wells, and submerged dams and sand reservoirs. Of these, by far the most important, is the storage of storm waters.

In many parts of the said region there are large areas in which the rain is not sufficient to form permanent streams, but where the only flowing waters are those of storm streams. These may be turbulent torrents during a few months of the year, but they are dry washes during the greater part. Now, as such streams have no commercial value beyond the amount of water they contain, their contents may be impounded in reservoirs during flood seasons and measured out at times of drought. In the "plains" these stored waters will be valuable, not only on lands where the crops are uncertain, but they will be useful also to reclaim certain lands that are now unproductive. The impounding and storage of the contents of temporary or storm-water streams presents no difficulties in the way either of engineering or of legal problems. The catchment basins are small in area and they naturally localize themselves as to distribution.

In the case of larger streams, however, especially navigable waters, the problem becomes so complicated that nothing short of national legislation will be able to settle the conflict of State and

private claims. For instance, a large part of the arid belt of Kansas will always be dependent on the waters of the Arkansas River for irrigation, but the only places where storage reservoirs can be constructed are high in the mountains in Colorado. That is, the Kansas farmer is as much interested in the proposed reservoirs at Twin Lakes as the Colorado farmer. Let us suppose that these reservoirs are constructed and the gates are closed for storage. This at once lowers the level of the stream, and cuts off the supply of water taken by a multitude of small ditches, whose head-gates are scattered along the river in the eastern part of Colorado. Now, inasmuch as the latter are prior rights, the courts of Colorado would sustain them, even though both parties to the suit were resident in Colorado—most certainly would they sustain them against the claims of the citizens of another State. Although the case mentioned is hypothetical, one such has already arisen. Some years ago the State of Nevada appropriated a large sum of money for the construction of storage reservoirs on Truckee River, the same being designed for the reclamation of land capable of a high degree of cultivation. After the surveys had been made it was found not only that the reservoirs must be located in California, but that the authorities of that State were ready to enjoin the construction of any scheme that would involve a change of water-level in California territory. The plans were, therefore, abandoned. There is another serious obstacle in the way of impoundment of storm waters, that may also be felt at a future time. Suppose that the storage of waters becomes so general that the navigation of any river, now classed as a navigable stream, is obstructed. It is hardly necessary to discuss what the final result would be. Or, were the storage of waters to affect the free navigation of a river like the lower Colorado, whose mouth, constructively, is in a foreign country; is there any doubt about the outcome of the question? But the Colorado is not the only river presenting an international question; the Rio Grande, the Columbia, and half a score of smaller streams possess each a wider field for conflict. In fact, there is not a river of magnitude in the arid region that may not bring about either interstate or international complications.

There is, also, a number of difficult problems that are purely

local to each of certain drainage areas. I take for illustration the drainage territory of the Rio Grande below White Rock Cañon. From the mouth of the cañon there are rich, reclaimable lands for a distance of nearly 200 miles below, unfortunately more than can be irrigated. Now, in the northern part of this area the river will afford irrigation for two acres to every one in the southern part. But at the present time the greater part of the cultivated land is in the southern end of the valley, and either their rights should be maintained or else equity should be the basis of their extinguishment. These conditions have already led to long-continued litigation, and in several instances shotgun injunctions have demonstrated that the people are mightier than the law.

Such complications cannot be wholly prevented, but their occurrence can be largely obviated. Their number will be reduced to its minimum only when the catchment basin of each stream, no matter whether in one State or a dozen, is under the control of the land-owners of that particular district. The water and the land must go together, and no water-owning corporations or companies should be permitted to exist under conditions by which the land-owner may be subjected to a corporation's cinch. Irrigable lands are dependent upon catchment areas where forests and grass are most abundant, and storage reservoirs must, therefore, be constructed, not on the irrigable lands, but high in the mountains; and, to get the full value of the waters, the lands themselves must be selected as near as possible to the reservoirs. Pasture and timber lands should be permanently reserved, and all reservoir sites, canal sites, and head-water sites should be placed under the control of the general government.

And here let us consider the question of artesian wells. No more water can be obtained from an artesian basin than is supplied to it; it is equally true that the number of wells in a given artesian reservoir is limited. A well discharging a cubic foot of water per second may afford sufficient water to irrigate two hundred acres; in the fruit ranches of Southern California it will supply the amount required by about seventy-five. Now if there were an artesian district that would furnish, from flowing wells, a second foot of water for every 200 acres, the problem of irri-

gating the arid lands would be an easy one. There would be no need of the 150 reservoir sites and irrigation districts the United States Irrigation Survey has located. It would not be necessary to impound a gallon of water, nor construct a yard of canal. But, unfortunately, not all artesian wells are flowing wells, nor do all the flowing wells yield an average of a second-foot of water; on the contrary, they yield but a small fraction of it. Furthermore, though the first wells driven in a district may be spouters, the driving of additional wells quickly reduces the pressure; the flow from the first wells diminishes little by little; the water-head is soon lost; and water must thereafter be obtained by pumping. So, instead of the seventy-five acres which the theoretical second-foot well is supposed to irrigate, the actual value is nearer five. In Southern California, in several instances, efforts have been made to force the yield of wells by means of powerful pumping machinery; but no matter how powerful the pump, water cannot be drawn into the induction pipe faster than the sand and gravel yield it. Moreover, if all the artesian wells used for irrigation throughout the whole world were assembled in a desert region the size of the State of Delaware, they would not supply it with the amount of water required to irrigate it. This statement seems pretty strong, but the statistics gathered by the Irrigation Survey bear it out. In Algeria 4,000 acres have been reclaimed by irrigation. In Southern California State Engineer Hall affirms that less than 3,000 acres have been made productive by irrigation. This, moreover, exceeds the acreage of all the other States and territories combined. And the moral is plain: artesian wells will afford only an infinitesimal part of the water required for irrigation.

There remain only the sand reservoirs and submerged dams to consider. The former present no problems essentially different from the catchment reservoir of an artesian district. The chief feature is the fact that a cubic foot of sand, saturated with the water it will hold by capillary attraction, becomes no inconsiderable reservoir when the number of cubic feet are multiplied. Unfortunately, the number of sand-valleys and basins is small, and their aggregate area inconsiderable. The submerged dam has even a more limited application, and so far has been

employed mainly in Southern California. Here there are many hondas, or narrow cañons, opening like immense crevasses into the mountain-ridges that rise abruptly from a recently-formed coast plain. The mouth of each is filled to a depth of many feet with coarse talus—the products of stream-corrasion. A stream, great or small, according to the season, flows on the surface of the talus. Beyond the mouth of the cañon it may flow onward to the sea, or it may be entirely lost in the sandy soil of the coast plain. Now, although the amount of water flowing in the stream-bed proper is great, that which sinks into the ground and finds it way along the sloping bedrock is still greater. If now a concrete dam be built across the mouth of the cañon, from bedrock to a few feet of the surface of the talus, all this seepage or underground water can be impounded and utilized. Thus the submerged dams do not differ in application from the storage reservoirs. In Southern California there may be an obstacle in the way that will either prevent their general use or else bring about expensive and protracted litigation. The seepage water, thus impounded, is the water that supplies artesian and all other wells; and inasmuch as nearly all the water that flows out into the coast-plain through these cañons will be cut off by the submerged dam, complicated litigation must result.

In the foregoing pages only the salient facts concerning the reclaimable arid lands have been given. These, however, are sufficient to demonstrate that the expense of reclamation is too great, and attended with too many legal complications to be undertaken by any other than Government authority. Even after water has been supplied to each reclaimable acre, the expense of application will materially enhance the cost of the crop. An acre of wheat, irrigated by artificial means, cannot well compete with one watered by rains. Not only are the arid lands deficient in natural waterways, by which crops are removed at the minimum of expense, but because of the lessened amount of product, railway tariffs must of necessity be greater. Furthermore, the cultivable areas being distant from one another, and therefore from a market, the matter of distance will materially increase the cost of transportation. Owing to the abnormal increase of the population of the world, the

value of food-producing lands is constantly increasing. When, therefore, the value of the grain-producing area of the United States has increased to an extent that the taxes absorb the greater part of the profit, food-crops will naturally seek the reclaimable lands of the arid region.

Because the area that is naturally irreclaimable is so great, it is evident that the western highlands of the United States will always be sparsely populated, and, compared with the Mississippi Valley, will support only a small fraction of the number per square mile that the latter will maintain. Its vast mineral wealth, however, will go a long way to make up for its food-producing deficiencies; and the development of its agricultural features will follow rather than precede that of its mineral wealth. The climatic conditions, humidity excepted, are generally favorable. Everything that can be cultivated between the latitude of Northern Norway and Southern Egypt can be grown in this region. Cotton, maize, wheat, barley, oranges, lemons, grapes, bananas and pineapples are among the facts; the possibilities are far greater.

XIX.

IMPROVEMENT OF THE MISSISSIPPI RIVER.

By Capt. Smith S. Leach, U. S. Engineer.

Read June 18, 1892.

The regulation of the Mississippi consists almost exclusively in the fixation of its banks and the confinement of its floods.

In river engineering a bank protection or "revetment" must extend from the top of the bank to a line a certain distance out in the bed of the stream. Cross-sections where caving occurs and where protection is required, are invariably of the triangular or V-shaped type. It is not far out of the way to assume that the maximum depth near the caving side represents locally the digging resultant in the regimen, and it is always desirable, and sometimes necessary, to carry the protection out under water to the line of Thalweg, since, if this be not done, it is certain that the Thalweg depth will be carried into the edge of the revetment as soon as the stream feels the restraint of an unyielding shore; and should the lower edge of the mat be found at a considerably higher level, a fatal undermining will occur.

The natural slope below the water's edge on the caving side is generally flat enough to be stable when protected. The slope above water is much steeper and sometimes practically vertical. The first operation is to reduce the latter to three and one-half or four horizontal to one vertical, which is done by streams of water under high pressure. This done, there is presented a long slope, extending from the top of the bank to the deepest water, and under three different conditions. The upper part of it, that above the maximum stages of the working season, is always dry. The lower part, that below the lowest stages, is always wet, while a zone connecting the two, that corresponding to the prevailing oscillations of stage during the working season, is sometimes dry and sometimes wet.

The lower zone being always under water, its covering must be built on the surface and sunk to its place. This requires a specially designed plant and methods of construction, and the

product is called the "sub-aqueous" or "river mat." The upper zone being always dry, a different plant and different methods of construction are demanded, and the product is called the "upper bank revetment" or "shore work." The middle zone, if wet, is covered by the sub-aqueous process, and if dry, by the other. If wet, the mats made and sunk to cover it are called "connecting mats," as they effect a junction between the sub-aqueous and shore mats; while, if it be dry (a rare occurrence), the shore work is carried over it, the middle zone for the moment disappears, and there is no connecting mat.

The *modus operandi* of protecting a caving bank is briefly as follows: The bank is first cleared, if necessary, back to a line a few feet in rear of where the top of the graded slope will come, and the hydraulic grading machines are then put to work. As soon as the graders have a start sufficient to enable them to keep out of the way, the *sub-aqueous* mat is commenced. Two or more extra strong barges are lashed end to end, so that their aggregate length equals or slightly exceeds the width of mat desired. This is, in most cases, 200 feet, being, however, in exceptional cases as great as 400 feet. This string of barges has strong timber-heads every 50 feet or so, on one side, and smaller timber-heads, every 8 feet, on the other. They are called "mooring barges" in the reports. The string, when made up, is placed along the bank with its down-stream end a short distance above the point selected for the head of the mat to rest. From the strong timber-heads, which lie next the bank, lines called "head-lines" are run ashore and secured to fastenings on the bank. Other lines, called "shackle-lines," are coiled on shore, the ends passed under the mooring barges, brought up on the outside and fastened temporarily to timber-heads. There are six to ten of such lines depending on the width of mat and strength of current, about 60 per cent. on the outer and 40 per cent. on the inner half of the mat. Their function will be explained later. A second string of barges of about the same length is made up and placed along the outer side of the mooring barges as the latter lie against the bank. This second string is composed of "weaving barges," which are peculiar only in having built on them a set of inclined ways, the rails of which are about 8 feet apart. The rails are ex-

tended at their lower ends beyond the gunwale of the barge, until their points nearly touch the water. A platform, inclined or stepped, is built on deck so that all parts of the ways are at convenient working height above it. When the weaving barges are placed in position as above noted, the extensions are next to, and their points touch, the mooring barges. Three or more long lines are coiled on the weaving barges, their ends passed under the platforms and made fast on the mooring barges.

All being in readiness, the up-stream end of this double string of barges is pushed out from shore until caught by the current, when, the lower end being held in, the whole plant swings round as the head and shackle-lines are paid out. This operation is called "swinging out," and is stopped when the outer end is 25 or 30 feet above a line drawn from the inner end, normal to the bank. The inner end is sparred out and everything made fast. There is no change in the handling of the shackle-lines, whether of manilla or metal. If wire ropes are used for head-lines, they are substituted for the manilla after "swinging out," being fastened to a collar on the timber-head and the slack taken ashore. Metal lines are greatly superior. The 25 or 30 feet deviation from a normal, is an allowance for the stretching and straightening, as the mat-building progresses, and a greater strain comes on them. For steel lines a much less allowance suffices. At the time of sinking the mat it is intended that the mooring barges shall lie normal to the bank. Barges of brush and poles are brought up and hung behind the weaving barges, and the construction of the sub-aqueous mat is begun. A pole is placed inclined alongside each rail of the ways, supported in place by brackets attached to the posts. These are called "weaving poles" or "weavers." A double line of heading poles is run across the lower ends (butts) of the weavers, and well spiked and wired to each.

Brush is then woven over and under alternate poles until the weavers are nearly filled. In strong currents extra poles are run across the head to increase its strength, upon which depends the safety of the mat at the most critical moment. The portion of mat built is now slid down the ways until the head lies against the down-stream-side of the mooring barges. Lines called "slip-

lines" are passed around the head poles, the ends made fast at the bottoms and the running parts at the tops of timber-heads on the lower side of the mooring barges. The head of the mat then hangs in a series of slings formed by the slip-lines.

The weaving poles are next spliced out by a second set of poles placed in the supports when the first ones were originally wired and spiked to the latter. Brush is woven in as before, until these also are nearly filled, when the lines on the weaving barges are slacked off. Impelled by the current, the weaving barges slide out from under the mat until the upper ends of the weavers are again near the foot of the platform, when the lines are caught up and the weaving barges held so that part of the mat floats on the water, the unfinished end only resting on the ways. The weaving poles are again spliced out and filled, and again the weaving barges are dropped down and a corresponding length run out on the water. The length slid off at once is 25 to 30 feet, and is called a "launch." This cycle of operations is repeated until a continuous mat of the desired length (1,100 to 1,200 feet usually) is woven and rests on the water. The lower edge is strengthened somewhat, but not so much as the head. It takes about ten working-days to weave such a mat. When about 100 feet is on the water, a top grillage is begun and kept up close to the weaving. It consists of a line of poles over each line of weavers, with cross-poles every 8 feet on the upper and every 16 feet on the lower part of the mat. All are well wired together, the stitches passing under the weavers.

When the mat is about half woven, coils of wire strand are run out along several (5 to 8) of the longitudinal grillage poles and fastened with a clamp and lashing at every intersection with a cross-pole. These are to prevent the mat tearing in two during sinking. They take the strain at each intersection, and transmit it directly to the head, where it is received by the shackle-lines and carried ashore.

As soon as the top grillage has progressed a short distance, pieces of strong rope are doubled and the ends worked into the mat for some distance, the bights presenting a small loop at the head. These are called "straps," and one of them is placed opposite the end of each "shackle-line" before referred to. A

steel shackle at the end of the shackle-line is engaged in the loop of the strap and the pin inserted. A line called a "pin-line" is attached to the pin to withdraw it when desired. The shackle-lines are now hauled on shore with a luff-tackle until they bear a good strain. They then take the pull of the mat directly ashore, relieving the head-lines to that extent.

When the mat lacks but two or three days of completion, ballasting is begun at the head. A barge of stone is made fast under the outer end of the mooring barges. The stone is wheeled out on to the mat as long as it will bear the weight of a line of men with loaded barrows. Especial attention is given to the head, which, held up by the slip-lines, is loaded until the latter are well stretched. The flotation of the mat is so far overcome that only the higher parts of the grillage poles are left above water. As this operation progresses, the rock barge is dropped down along the outer edge of the mat, and it is so regulated as to gain on and finish a few hours after the weaving.

The operation of sinking, which now follows, is the critical one. It will be remembered that the head of the mat is now harnessed, so to speak, in two sets of lines—the shackle-lines, which, re-acting against the current, prevent horizontal movement, and the slip-lines, which, when put under strain by loading the head, hold it in a vertical direction. The slip-lines are slacked off until the head of the mat, for some 100 feet, is 4 to 6 feet under water. Barges of stone are run into the open water space thus provided, and lashed end to end to equal the width of mat. They are attached to the mooring barges by three long lines coiled on the rock barges. A line of men is stationed along each gunwale of the rock barges and all the lines are manned. Everything being in readiness, the men begin to throw rock over onto the mat. The slip-lines are slacked off gradually, and the head of the mat descends toward the bottom, the shackle-lines going down with it. As this takes place, more and more of the mat goes under, leaving more clear water below the rock barges into which the latter are allowed to drop down, rock being thrown off as they pass over the mat. This is continued until the rock barges have passed over the mat from head to foot, and it lies on the bottom. During sinking, the mat is controlled from

the head like a flag flying in a strong breeze. The process is in its nature one of excitement and some confusion, especially with negro laborers, who cannot be induced or compelled to throw over rock without shouting and singing at the top of their lungs. When the mat is down, however, account of stock is taken, and if it be found that less than the desired amount of stone is on the mat, a barge is again floated over it and the deficiency made up.

As soon as the mat is down, the slip-lines are withdrawn, the shackle-lines are slacked off a little and then the pin-lines are hauled until the shackles are free, when the shackle-lines are hauled in. The mooring barges are swung into the bank, and the whole operation described is repeated.

The construction of the shore work is much simpler. Poles and brush are brought to the bank on barges. Stakes 3 feet long are driven into the ground normal to the graded slope at intervals of 8 feet in each direction. They project about 2 feet and mark the intersections of a rectangular grillage of poles wired together at splices and intersections.

A strong lashing of wire is passed around each intersection, its ends being brought up to the top of the stake and fastened. A layer of brush is then placed in the direction of one diagonal of the grillage and a second layer on top of it in the direction of the other diagonal. A top grillage is then laid with its intersections at the tops of the stakes, from which the ends of the lashings are recovered and passed around the corresponding intersections, making a through and through fastening, binding the whole firmly together. The ballast is wheeled out and distributed by hand.

When there is a gap between the shore work and the sub-aqueous mat, as is usually the case, a weaving barge is run in against the bank with the points of its ways touching the lower edge of the shore work. The mat-head is dropped off and well fastened to the shore work and the barge sparred out for another launch, and this operation is repeated until the "connecting mat" is long enough, so that when sunk its outer end will lap 5 to 10 feet on the inner edge of the sub-aqueous mat. The weaving barge drops down its length and builds another mat below and adjacent to the first, and so on until the space is covered.

These mats are fastened together at their adjoining edges, ballasted and sunk.

During the last season's operations which I conducted, I introduced a modification, having for its object to dispense with the connecting mat as a separate feature. The shore work was connected with the inner edge of the sub-aqueous mat before sinking, carried across the variable width of intervening water and up the bank to a plane above all seasonable stages, leaving its completion till the latter part of the season, when other work could not be done. In passing over the water, inside the river mat, the shore-work methods were used, the men being supported on planks laid on the bottom grillage poles. This construction, or something developed from it, will, I believe, prove greatly superior to the former method. Poles and brush are obtained along the river, willow being mostly used. Poles are 4 to 8 inches at butts, 25 to 30 feet long, and cost, delivered in government barges at contractors' camps, $1.50 to $2.25 per cord of 128 cubic feet. Brush is $1\frac{1}{2}$ to 4 inches at butts, 25 to 40 feet long, and costs about $1.25 per cord loaded at camps. Five feet are deducted from gross length in measuring brush. The stone used is a medium limestone, quarried on the Mississippi and Ohio rivers within 100 miles of their junction. It can be obtained by contract, at and above Memphis, at about $1.50 per cubic yard (about a long ton), delivered at works on contractors' barges. Galvanized annealed Bessemer steel wire is used, Nos. 10 and 12 mostly. The strands used are 19 wire, 4 inches lay, $\frac{1}{2}$ and $\frac{5}{8}$ inch diameter. Other articles used are of standard commercial grades and dimensions.

Revetment of standard strength and of the width prevailing in the upper half of the river requires about $1\frac{1}{2}$ cords of brush to the running foot. The proportions of other materials used with one cord of brush are:

Poles,	0.16 cords.
Stone,	0.85 cubic yards.
Wire,	8.07 pounds.
Wire Strands,	1.4 "
Spikes,	1.1 "
Iron,	0.26 "

BANK REVETMENT, MISSISSIPPI RIVER.

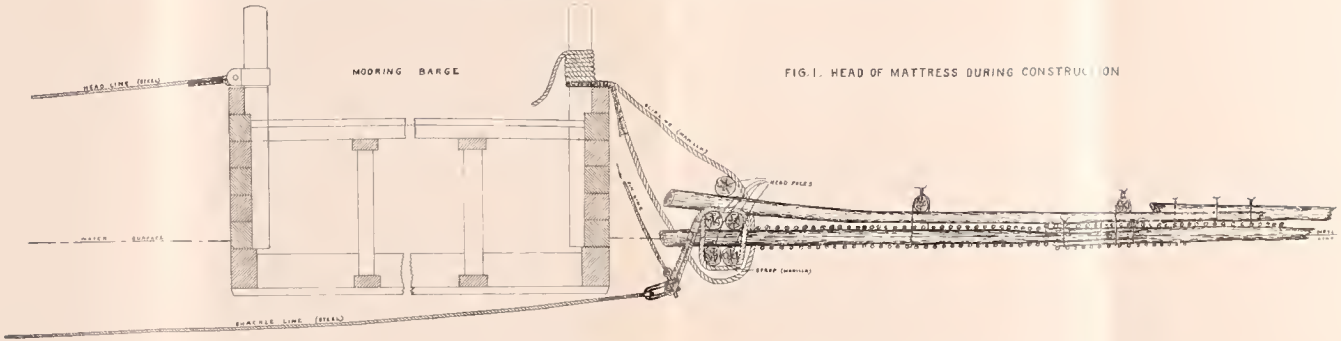


FIG. 1. HEAD OF MATTRESS DURING CONSTRUCTION

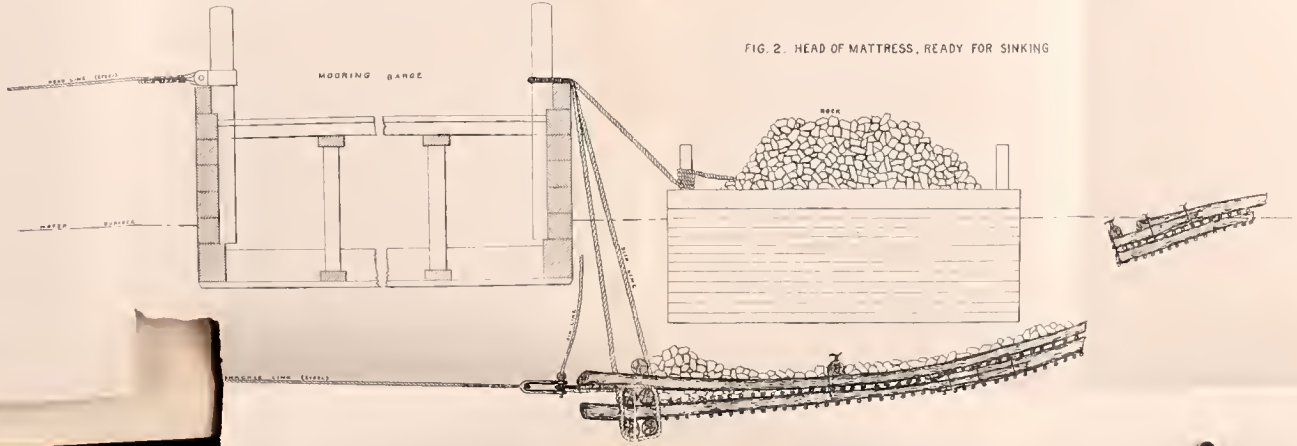


FIG. 2. HEAD OF MATTRESS, READY FOR SINKING

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Coal,	2.6 bushel.
Lumber,	0.9 feet B. M.
Rope,	0.13 pounds.

The following percentages were realized during the season of 1887–8 under average conditions and prices:

Item.	Percentage of Cost.
Labor (including subsistence),	44.67
Poles,	4.09
Brush,	17.80
Stone,	19.52
Wire,	4.88
Wire Strands,	1.01
Spikes,	0.49
Lumber,	0.35
Coal,	5.32
Iron,	0.10
Rope,	0.22
	100.00

The percentages of cost of different parts of the same work were:

Sub-aqueous and connecting mats,		35.94
Clearing,	0.56	
Grading,	4.57	
Mattress,	39.40	
Total shore work,		44.53
In direct costs, divisible *pro rata* between the above,		19.53

XX.

YEARLY TIDES.

By W. S. Auchincloss, Active Member of the Club.

Read April 2, 1892.

The phenomena of daily tides are well understood, and their effects at seaside towns forecast with great precision. We propose to show in the present paper that confined bodies of fresh water are subject to yearly oscillations, similar to tides of greater or less magnitude.

In March, 1885, we had occasion to sink a well for household purposes at "Hill Crest," Bryn Mawr, Pa. Natural anxiety as to the permanence of the supply, led us to observe the depth of the water at intervals of say ten days apart. It soon became evident that the water was receding, and the depths were kept with greater care. We then arranged a float in the well and recorded the readings at the curb-line.

In 1886 there was a gratifying rise of the surface and a total gain of 12 feet. Our curiosity was now aroused and we determined to study the law—if such a law existed—of this ebb and flow. These observations have been continued during the past seven years, through both seasons of drought and of remarkable rainfall, so that we now feel warranted in presenting the facts and drawing some general conclusions. During the entire period there has been an average draught from the well of 55 gallons per diem, say 20,000 gallons per annum; the rest of the water necessary for household purposes has been gathered from neighboring roofs, and this accounts for the small draughts made on the well itself.

That you may better understand the physical characteristics of Hill Crest well, we note that the soil for a distance of 14 feet is of a magnesian or talcose nature, only slightly pervious to water; the remaining 50 feet is a hydro-mica schist, more or less decomposed near the surface, but only removed by blasting at lower depths. Occasional crevices and fissures were met, and at almost all points the rock was so laminated that a penknife-blade could

with ease be imbedded in the direction of the strata. The dip was to the southeast, with an angle of 80° from the horizon, trending northeast and southwest. The weight of the rock is 163 pounds to the cubic foot. Specific gravity 2.81. As to location, the top of the curb is 435 feet above the level of the ocean. This is higher than any point in the neighboring country, and the hill itself is 120 feet above the adjoining valley.

The well was dug to a depth of 64 feet, with a diameter of 6 feet, and lined with broken stone the entire distance; the last 10 feet being laid in cement, so as to exclude all surface-water and foreign bodies. The average inside diameter is about 4 feet 9 inches, and the water section equals $17\frac{8}{10}$ square feet. When finished the water rose to a depth of 13 feet. It is exceedingly pure and palatable, with an average temperature of 53°, being only one degree colder in winter and one degree warmer in summer. It is interesting to note that the average atmospheric temperature in this latitude is also 53°.

From observations taken at the Pennsylvania Hospital, Philadelphia, during the past seven years, by Mr. Benjamin Shoemaker, druggist, we learn that in:

1885	rainfall = 40.70 inches.	1889	rainfall = 60.54 inches.
1886	" = 46.35 "	1890	" = 41.08 "
1887	" = 48.02 "	1891	" = 45.60 "
1888	" = 49.91 "		

Giving an average of 47.5 inches.

As to distribution of the rainfall we learn from the reports of Mr. John E. Codman, civil and mechanical engineer, Philadelphia, containing eight years' observations on the stream-flow of the Perkiomen, the Neshaminy and the Tohickon, that probably 50 per cent. of the rainfall at Hill Crest flows away over the surface of the ground to the adjoining valley. Doubtless 40 per cent. is taken up by vegetation and surface evaporation and 10 per cent. only sinks deep in the ground, from which 3 per cent. is drawn for household purposes.

During periods of drought the supply is withheld and the water falls below the normal (see record for 1885). In 1889 the supply was excessive and the ground correspondingly flooded. The effect of these abnormal conditions impresses itself on the

succeeding years. The normal action is best shown by the record for 1888 given below:

1888	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	′	′	′	′	′	′	′	′	′	′	′	′
Flow and Ebb . .	0.5	1.0	2.0	3.5	5.5	6.0	5.5	4.5	3.0	2.0	0.5	0.
	″	″	″	″	″	″	″	″	″	″	″	″
Rainfall	4.9	2.6	6.6	2.5	4.1	1.5	3.6	6.3	6.5	4.0	4.0	3.3
	°	°	°	°	°	°	°	°	°	°	°	°
Tempt. of Air . .	28	34	35 Bliz.	51	61	73	72	73	64	50	46	36

From which we learn that in normal years the surface of the water reaches its lowest level in the month of December. That it steadily rises during the spring months, attains an elevation of 6 feet in the month of June and descends during the autumn. If we search the cause of this alternate flow and ebb in the rainfall, we will find that while 22.2 inches of rain fell from January to June, the well-water *rose* 6 feet; per contra 27.7 inches of rain fell from June to December, and the well-water *lowered* 6 feet. Evidently we must look for our explanation in another direction, for if the 6 feet rise was due to rainfall then we ought to have noted a rise of over 13 feet by December. Again, the rise cannot be due to differences of atmospheric temperature, because the temperature of the well-water practically never changes; no more does that of the rock in which the water is confined. Neither does evaporation form an important factor, for the temperature of the well-water being constant, whatever evaporation takes place must be during the summer months, and this would cause a falling of the waters instead of a rise. Nor can we discover any adequate cause when viewing the subject from a barometric standpoint. We believe that the true cause of this *yearly oscillation* in the well is a resultant of the influences of gravity and the sun's attraction at different seasons of the year. When the sun reaches its furthest point south of the equator, gravity exerts its maximum influence on the waters of the Northern Hemisphere and centrifugal force its minimum; but when the sun returns in June, it exerts its force directly in opposition to gravity and centrifugal force then exerts its maximum influence. It follows that in December the waters in the earth will be drawn into the minutest crevices and

their surface lowered; but in June they will in a measure be released, and under the influence of adhesion and friction will be held at a higher level than at any other season of the year. Naturally, like events in the Southern Hemisphere must occur in the reverse order of those in the Northern.

We have proved by experiments on the 22d of December, if we pump 16 feet of water (say 2,200 gallons) from Hill Crest well, that in 102 hours the water will recover its former level, and no more impression will be produced than by the removal of a bucket of water from a pond.

It only remains to add, that frequent observations have been made with great accuracy, to determine whether the waters of the well showed any signs of flow or ebb, when the ocean tide was either high or low at Sandy Hook, New York; but never have we been able to discover the faintest trace of a daily oscillation in the waters of Hill Crest well.

Having watched the yearly oscillation, and attempted to account for the ebb and flow, we were curious to learn how far like phenomena had been noted in other countries.

Baldwin Latham, Esq., President of the Royal Meteorological Society of Great Britain, kindly favored us with a copy of his address, delivered November, 1890, on the "Relation of Ground Water to Disease." He stated as follows:

"The free water of the ground is a very active agent and may become the direct vehicle for carrying the active properties of disease. The free ground water rises and falls, as a rule, every year.

In the year 1829 the records of the well at Hartlip Place show that there was *no* low water at the usual period in that year. The water rose continuously through the year, up to June, 1830, and so too with other years in modern times, such as the years 1860 and 1879, when a similar state of things existed, and these are all healthy periods. We have in many parts of the country complete records of underground water which carry us back beyond the date where registration of deaths commenced," etc.

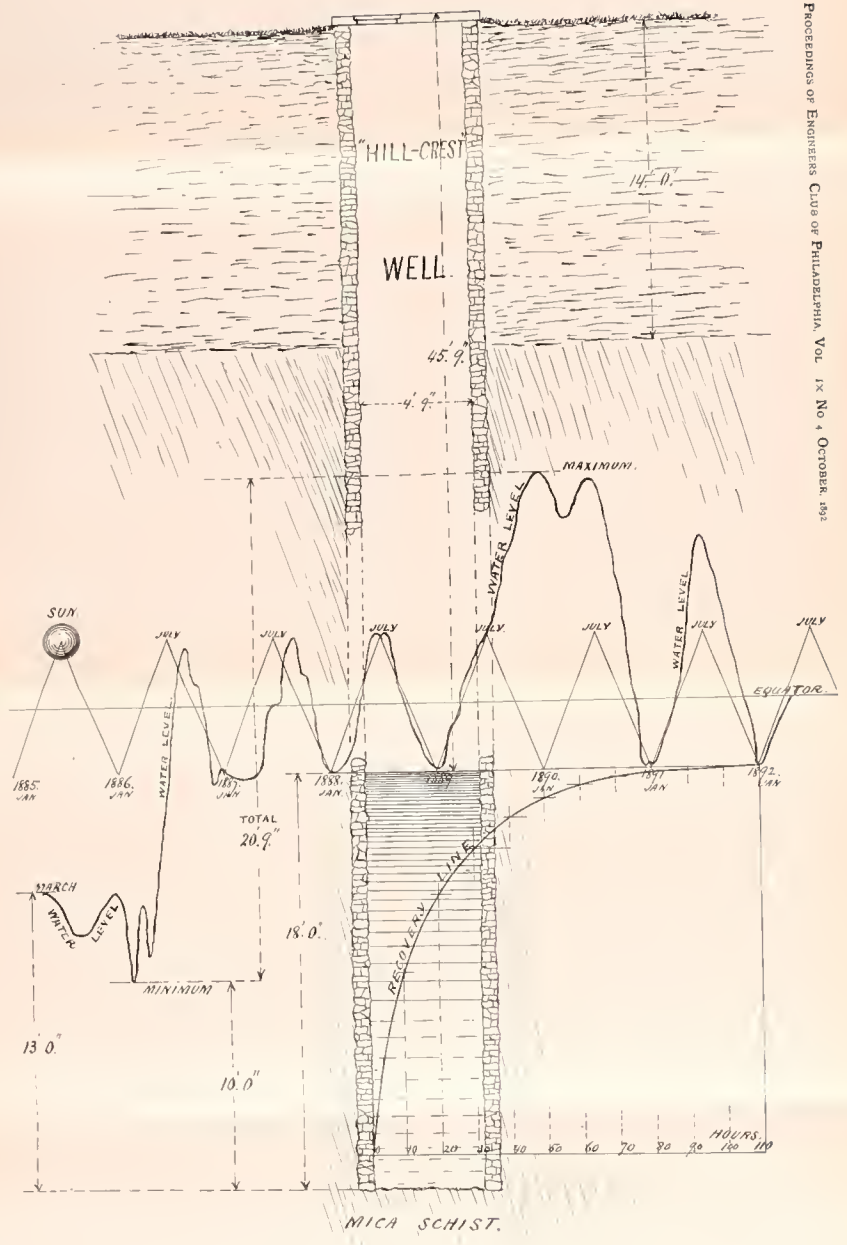
Mr. Latham also referred to the records of wells at Chichester, at Durham and at Croyden. Although his studies related more particularly to the questions of public health, yet he made it

quite evident that many wells in Great Britain are characterized by phenomena similar, if not identical, with those we have just considered in the case of Hill Crest well. This unexpected uniformity in countries three thousand miles apart, suggested a possibility that the great lakes of our own country would also show a yearly oscillation. Happily for us the United States Engineers have kept accurate records for the past twenty-eight years, and the State Weather Service of Wisconsin has made observations for twenty years also.

From these sources we cull the following data relating to Lake Michigan:

1860-1887	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
		"	"	"	"	"	"	"	"	"	"	"
Flow and Ebb. .	0.	0.5	2.6	5.2	8.3	11.	12.	11.5	9.0	6.4	3.3	1.2
	°	°	°	°	°	°	°	°	°	°	°	°
Tempt. of Air . .	18.6	23.0	30.2	43.2	53.4	62.7	69.4	68.1	61.0	49.8	36.2	26.3
	°	°	°	°	°	°	°	°	°	°	°	°
" " Lake .	32.6	33.2	35.0	42.4	49.8	56.0	62.5	66.3	60.9	50.7	41.4	34.4
	"	"	"	"	"	"	"	"	"	"	"	"
Rainfall	2.2	1.9	2.5	2.8	3.4	3.9	3.3	3.0	2 9	2.6	2.0	2.0
		"	"	"	"	"	"	"	"	"	"	"
Evaporation . .	0.	0.2	0.5	1.5	2.7	3.6	4.5	5.2	4.5	2.8	1.4	0.

We have ventured to estimate and include the item of evaporation with the above data, in order to show that the rise of the lake would have been much greater, if, as in the case of well-water, there had been no evaporation. The total evaporation was counted at 27 inches, which is 85 per cent. of the annual rainfall. This factor was derived from the experiments made by Mr. Desmond Fitzgerald, civil engineer at Chestnut Hill Reservoir, Boston, Mass. The total quantity we have distributed among the months in proportion to the number of degrees the temperature of the lake exceeded 32°. It is self-evident, therefore, that a yearly oscillation exists in Lake Michigan, that the average rise and fall is 12 inches, and that the seasons of high and low water correspond with the summer and the winter solstice. The data for Lake Huron is the same. The yearly oscillation in the surface of Lake Superior averages 13 inches, and that of Lake Erie averages $15\frac{1}{4}$ inches.


"HILL-CREST"
WELL
14'-0"
45.9"
4'.9"
MAXIMUM.
WATER LEVEL
SUN
JULY
JULY
JULY
JULY
JULY
WATER LEVEL
JULY
JULY
EQUATOR.
1885. JAN
1886. JAN
WATER LEVEL
1887. JAN
1888. JAN
1890. JAN
1891. JAN
1892. JAN
TOTAL 20.9"
MARCH
WATER LEVEL
18'.0"
MINIMUM
RECOVERY LINE
13'.0"
10'.0"
HOURS.
0 10 20 30 40 50 60 70 80 90 100 110
MICA SCHIST.

So far as we are aware no reliable data exists for smaller lakes, but enough has been given in this paper to substantiate our claim, that "confined bodies of fresh water are subject to yearly oscillation of greater or less magnitude," and we are confident that more extended research will secure as complete a recognition of *Yearly Oscillation*, as Physical Geography has always accorded to the phenomena of daily tides.

NOTES AND COMMUNICATIONS.

ACCIDENT TO A BUCKEYE ENGINE.

By W. H. Francis, Active Member of the Club.

Read March 5, 1892.

I submit for those members interested, a Gib and Key, showing how they have been compressed cold, by water in cylinder of an 18-inch Buckeye Engine.

The engine was running about 100 revolutions per minute, and the accident occurred as the engine was moving forward, and evidently culminated at or near extreme stroke, so that the connecting rod received the strain, without tendency to buckle. This Gib and Key were in the cross-head end of connecting rod, and an examination showed that neither piston-rod nor cross-head were injured, although the strap was distorted, as shown in sketch herewith.

It might be asked, How could an engine, properly piped, get such a "shot of water" as this one evidently did? The answer in this case is quickly given: a new fireman having pumped up the feed-water until it was out of sight in the water-gauge, concluded it was time to creep on top and lift the safety-valve. The engine soon found where the water was, though I fear the fireman did not.

I also send a section cut from an 8½-inch steel shaft. This shaft, when finished in the shop, showed no sign of seam or crack, but appeared to be perfect. After running a few days at 96 revolutions, the heat generated in the main bearing of engine caused it to open, presenting a knife-edge in the direction of rotation, cutting out the Babbitt first and then expanding sufficiently to burst the pedestal cap, tear out the stud-bolts from the pedestal itself, and bend the crank-pin.

Upon examination the shaft showed the pocket or false weld to be 5 inches long and about central with the main bearing—the balance of the shaft was good. Had the flaw been in any other position, it probably would never have been discovered.

A NOTE ON ENGINEERING CIVIL SERVICE.

By Gratz Mordecai, Active Member of the Club.

Read April 2, 1892.

A short time ago I was an interested listener to a lecture, delivered by an agreeable Oxford professor, which was intended to present the different theories of the advocates of Individualism or Corporations, as distinguished from the theory of Socialism or Governments, in the management of matters affecting the wants of the people.

There seems to be one thing, however, on which all theorists are of the same mind, and it is becoming pretty generally agreed, that turnpike companies and toll-bridge companies must give way to the local government in the matter of managing the public highways and roads, where every one should be free to come and go in that way which may best fit his fancy or his purse; and I think it may be of some

interest to note just how they look after these things in other countries. About ten years ago I was associated in the construction of what is now an important railroad, in the State of New York, with a young Scotchman who had, a short time before, been an honor graduate of the Engineering Department of Edinburgh University, and was, I well remember, an admiring student of Fleeming Jenkin. As might be expected, we found him a bright and ready mathematician, a neat draughtsman, and a hard and willing worker, showing good training, and he was anxious to get practice.

After about five years' experience in the office and in the field, in the United States and Canada, he returned to Scotland, and we heard shortly after that he had passed a severe examination and had entered the Civil Service of Ireland.

Exactly what inducements there were for a Dundee Scotchman to join the Irish Civil Service, and just what he was to do after he got there, were matters about which I had a very indistinct idea until not long ago I received a pleasant letter from him, dated Belfast, in which he said: "I have now charge of County Down, which is one of the best, if not the premier county in Ireland. I have ten assistants, and in my care are 2,800 miles of roads, some harbors, courthouses, etc. I have something to do with a railway now being built in the county, and so am not forgetting all I learned with you. My work is pretty heavy at times, but I can get holidays whenever I want, almost, and have to ask leave from no one."

Here, where we are apt to look upon Ireland as one of the worst-governed of modern civilized communities, we can show no such organized administration of public works and property; and though we may compare with great satisfaction the general prosperity and success of the Government of Pennsylvania, with the general lack of both in the government of Ireland, it only renders the comparisons, in this regard, the more striking. To be sure, I am aware of the influence of public demand, of natural characteristics and resources, of the cheapness of labor, and of the scarcity of railroads, in the question of establishing and maintaining a proper system of public roads; but will it not, after all is said, depend very largely upon the intelligent and honest expenditure of public money, under the supervision of men technically able to do the best for the public? It is quite likely that my friend's 2,800 miles of roads in County Down will compare very favorably with the streets even of the county of Philadelphia, and I thought it might be well, in these days of an awakened interest in public highways, to note again, what we have all heard before, the difference between a practical Civil Service, as shown by the carefully-selected civil engineers of Ireland, and an impracticable and unpractical Civil Service, as illustrated by the, generally, purely political road supervisors of Pennsylvania. County Down lies on the east coast of Ireland, just south of Belfast, and its coast is deeply indented by the Irish channel, and it seems well watered and supplied with railroads. Its population in 1841 was about 360,000, and in 1891 about 260,000 with no very large towns. Its area is between 950 and 1000 square miles, which, with the length of roads stated, would give almost exactly 2 diagonals in every square mile, or if evenly distributed, the roads would cut the land up into squares of about 3,700 feet on the side. This area is just about equivalent to that of our own adjoining counties of Chester and Delaware, which have a population of 160,000 or thereabouts.

Leaving out what may be called the abnormal growth of Philadelphia—that is its excess over Dublin in population—there are about the same number of people in Pennsylvania, with its nearly 45,000 square miles, as in Ireland, with its not far from

32,000 square miles. If you think it is worth while I will try to get for the Club some further information about the service and about the work, specifications, etc.

DISCUSSION.

Robert A. Cummings: While the gist of Mr. Mordecai's interesting paper is that of an "Engineering Civil Service," such an opportune subject should not be dropped without considerable discussion, and, if possible, positive action by the Club should be made to secure the ideal ends outlined therein. Nothing would be more beneficial to the community at large, and certainly nothing more beneficial to Civil Engineering in general, than their elevation as authorities commanding the respect and admiration of their constituents through the "visible standards of the intelligence of the people."

Mr. Mordecai has referred in detail to the Irish Civil Service, or rather Local Government. Perhaps it would not be amiss to here quote a portion of Consul Magahan's recent report on Irish highways. As to their government, he says: "In Ireland the construction and maintenance of the public highways, throughout suburban and rural districts in each county, are regulated by means of the grand jury presentment system. Every county is divided into baronies, and in each barony a presentment sessions court is held twice a year, the persons composing the court being the magistrates residing in or having property and jurisdiction in the barony, and a number of the resident rate-payers in the barony—the latter being nominated by the grand jury of the county at the previous county assizes.

"Previous to each presentment sessions all applications for the construction of new bridges and roads, or the maintenance of existing roads and bridges within the barony, are lodged with the secretary of the grand jury, who classifies the applications and attends with them at the court, where they are examined and approved of or rejected. Advertisements inviting tenders for all such works as have been approved of are then issued and a day for the consideration of the tenders is fixed (this being called the 'adjourned road sessions').

"The county surveyor, who is the engineer in charge of all the highways, bridges and other public works in the county, prepares the necessary plans and specifications, and when, after an interval of three or four weeks, the court—'the adjourned road sessions'—reassembles, all tenders sent in are examined and the several contractors declared—each contractor having to enter into a bond, with sureties, for the due execution of the work.

"A list of the contracts thus (provisionally) entered into, giving contractor's name and a brief description of the work as to length, width, material and contract price, is then printed for the information of the grand jury at the following assizes, when, if approved of, they are laid before the judge and 'fiated' or finally confirmed. . . . . In this way every barony supports its own roads and bridges, except mail-post roads, which are charged half on the barony and half on the county at large. . . . . The county surveyor is assisted by six or more deputies, in proportion to the area of the county. . . . . Appeal on the part of rate-payers against the county surveyor's certificate for payment to any contractor may be made to the grand jury at the assizes, when all grounds of complaint would be inquired into, and, if necessary, to the judge."

From this, then, it is easier to see the reason why Mr. Mordecai's friend's "2,800 miles of roads in County Down will compare very favorably with the streets, even of the county of Philadelphia," and this in "one of the worst-governed of modern civil-

ized communities." There is a little ambiguity about Mr. Mordecai's remarks on this point, and I cannot but take exception to his hazardous statement—because of the lightning speed at which the New World is traveling, politically and socially, and where improvement is the order of the day. Further it would be interesting, apart from the "Engineering Civil Service" question, to remind Mr. Mordecai that his striking comparison, which he gives with "great satisfaction," that "the general lack of prosperity and success in the government of Ireland" is not borne out by facts developed since 1886, and now being realized in 1892. However, to be more patent to the subject—which should command the serious thought and encouragement of the engineering fraternity—it is self-evident that if engineers are to realize the full benefits from such a movement, it is necessary that they take the initial step and inaugurate the ways and means by which the object is to be accomplished; and for the purpose of the members of this Club forming a better opinion upon the desirability for a change in the present system of making and maintaining public roads, I would only suggest the appointment of a committee to report upon the system of Pennsylvania.

ABSTRACT OF MINUTES OF THE CLUB.

From January to June, 1892, inclusive.

JANUARY 2, 1892.—Regular Meeting.—Past President Henry G. Morris in the chair. About thirty persons present, including two visitors.

Mr. F. H. Lewis concluded the discussion of his paper on The Use of Soft Steel in bridges and the accompanying Specifications for First-Class Bridge Superstructure.

The Secretary read, for Mr. Emile Low, Active Member of the Club, a paper entitled A Large Land Slide. Discussion by Mr. E. V. d'Invilliers.

The Secretary announced that the chair had appointed the following gentlemen to constitute the Committee to consider the advancement of the social feature of the Club: Messrs. Howard Murphy, *Chairman*, Henry G. Morris, R. J. Parvin, W. J. Hoyt, H. C. Lüders, R. P. Snowden, Geo. A. Bullock, J. F. Stevens, Morris W. Rudderow, Jos. J. de Kinder and Carl Hering.

JANUARY 16, 1892.—Fourteenth Annual Meeting.—President Wilfred Lewis in the chair; 69 persons present, including 6 visitors.

The Retiring President, Mr. Wilfred Lewis, delivered the Annual Address.

The Secretary read the Annual Report of the Board of Directors. This document reported a very marked increase in the activity and prosperity of our organization, and referred to the adoption of the new Constitution and By-Laws, on March 7th, as the most notable feature in the year's history, and as undoubtedly marking a turning-point in the progress of the Club.

The setting apart of certain meetings for the consideration of selected subjects, and the advance publication of papers or abstracts in the notices of meetings, have brought about an increase of about 100 per cent. in the average attendance.

The Publication Committee of the present Board issued four numbers of the Proceedings during the year 1891, and a fifth number during the first few days of January. The following number, Volume IX, Number 1, is being actively prepared. The receipts from advertisements during the past eight months have been nearly doubled, and they now approximately cover the cost of publishing the Proceedings. The volumes of the Proceedings now consist each of the four quarterly numbers issued under date of one calendar year, and the subscription price to non-members has been reduced from $5 per volume of 5 numbers to $2 per volume of 4 numbers, in the hope of increasing our subscription list.

Important improvements have been made in the arrangements of the Club House, including the fitting up of a card and chess room, and the introduction of a telephone.

During the year, and since the issue of the last printed list, dated June, 1890. forty-seven Active and three Associate members have been admitted, and the resignations of twenty-four Active and three Associate members have been presented and accepted. The Board is advised of the death of three members during 1891, viz.:

Moncure Robinson, Honorary Member, elected April 6, 1878, died November 10, 1891.

S. Craige McComb, Active Member, elected November 1, 1884, died February 18, 1891.

R. H. Lee, Active Member, elected November 19, 1881, died December 28, 1891.

Our list of members at the close of 1891, after deducting all losses by deaths, resignations and delinquencies, stood as follows:

	Resident.	Non-resident.	Total.
Honorary		1	1
Active	238	169	407
Associate	11	2	13
Total	249	172	421

Subscriptions to the amount of $313.50 have been received in aid of the proposed Engineering Headquarters and Engineering Congress at the World's Columbian Exposition in Chicago, in 1893.

Here followed a list of 48 papers, etc., presented during the year.

The Report closed with an announcement of the incorporation of the Club, and of renewed hope in its future.

The Treasurer reported that upon assuming control of the accounts of the Club, the assets were as follows:

Cash received from ex-Treasurer		$ 170 63
Amounts due from advertisers, etc.		753 00
Arrears of dues for periods ranging from 1882 down	4,365 46	
		$5,289 09

The liabilities of the Club at that time, so far as could be ascertained, including the estimated cost of printing five numbers of the Proceedings, then either in arrears or due in 1891, $4,437, leaving an apparent balance of assets $851.82; but of the amounts due from members $2,282.76 proved uncollectible, and the amount due from members in good standing was thus reduced from $4,365.46 to $2,082.70, and instead of a credit balance of $851.82, there was a deficit of $476.67.

Seventeen members, whose arrears of dues amounted to $274, were dropped from the rolls at the end of 1891, as being two years in arrears. Since April last, 40 Active and 2 Associate Members have been admitted, whose initiation fees and dues amounted to $550, and have nearly all been paid.

The Club enters upon the year 1892 with assets in cash and collectible accounts amounting to $1,662. The total present liabilities, as far as known, are $2,170.56, showing a deficit of $508.56.

The Tellers of election reported, through Mr. A. Falkenau, Chairman, 137 legal votes cast, and the following gentlemen elected members: Active Members, Messrs. Thos. C. McBride, F. R. Ford, Edward K. Landis, Richard Collier St. John, Wright L. Parvin, Joseph Hartshorne, William H. Thorne, Jay M. Whitham, William W. Hill, J. A. Colby, Charles E. Ross, Chas. Edgerton, J. Chester Wilson, John F. Haskins, Louis Y. Schermerhorn, J. Sellers Bancroft, William H. Norris, Wm. J. Donaldson, Carl Jacobsen, Henry Leffmann, S. M. Vauclain, Thomas D. Whitaker and S. H. Jencks; Associate Member, Mr. Andrew Brockerhoff.

133 legal votes were cast for officers, and the following gentlemen elected:

President,
James Christie.

Vice-Presidents,
Frederick H. Lewis, Pedro G. Salom.

Secretary,
John C. Trautwine, Jr.

Treasurer,
T. Carpenter Smith.

Directors,

John E. Codman,	Wilfred Lewis,
George V. Cresson,	H. W. Spangler,
Strickland L. Kneass,	David Townsend.

The Secretary read a letter from A. J. Rudderow, Esq., reporting that on January 9th the proposed charter of the Engineer's Club, as amended, was granted by the Court of Common Pleas, No. 4, for the County of Philadelphia, and that on the 11th inst. said charter was lodged with the Recorder of Deeds for record. Mr. Rudderow suggested that the Club formally accept and ratify the charter at this meeting, and adopt the By-Laws as they now exist, until such time as they can be revised and amended to conform to existing conditions.

The following is an abstract of the charter:

"WHEREAS, we, the undersigned, citizens of the Commonwealth of Pennsylvania, whose names are subscribed to this Charter or Certificate of Incorporation, have associated ourselves together for the purposes and upon the terms and by the name herein stated, under the provisions of an Act of the General Assembly of the Commonwealth of Pennsylvania, entitled an Act to provide for the incorporation and regulation of certain corporations, approved the twenty-ninth day of April, in the year of our Lord one thousand eight hundred and seventy-four, and the several Supplements thereto, we do therefore set forth and declare that

1

"The name of the Corporation is 'The Engineers' Club of Philadelphia.'

2

"The purposes for which this corporation is formed are to promote the Arts and Sciences connected with Engineering, by means of periodical meetings for the reading and discussion of professional papers, and the circulation by publication among its members and others, of the information thus obtained, and for social intercourse.

3

"The business of the corporation is to be transacted in the City of Philadelphia.

4

"The corporation shall have perpetual succession by its corporate name.

5

"The officers of the corporation shall be a President, two Vice-Presidents, a Board of Directors and such other officers as the corporation may, from time to time, appoint. The time and manner of holding the elections, and the terms of office of the several officers may be prescribed by the corporation.

6

"The corporation shall have power to hold and transfer such real and personal property as the purposes of the corporation may require; *provided*, that the clear yearly value or income of the real estate shall not exceed twenty thousand dollars.

"The officers of the corporation who are chosen to serve until the annual meeting

in the year 1892, which shall be held at the time and place to be determined by the By-Laws of the corporation, are as follows:

President,
Wilfred Lewis.

Vice-Presidents,
David Townsend, S. H. Chauvenet.

Secretary,
Howard Murphy.

Treasurer,
T. Carpenter Smith.

Directors,

Rudolph Hering,	P. G. Salom,
J. C. Trautwine, Jr.,	F. H. Lewis,
H. W. Spangler,	G. S. Webster.

"At the said annual meeting in the year 1892, the corporation shall elect a President, two Vice-Presidents and such other officers as may be fixed by the By-Laws. One Vice-President and three Directors, to be determined by lot, are to serve two years, and all other officers then elected are to serve one year. At the annual meeting following the said annual meeting of the year 1892, and each year thereafter, in addition to the officers to be elected annually, a Vice-President and three Directors are to be elected to serve two years."

On motion of Mr. Coleman Sellers, Jr., the Charter was accepted and ratified, and the present Constitution and By-Laws adopted.

The Secretary read an amendment to Article III, Section 2, of the By-Laws, proposed by Mr. E. V. d'Invilliers at the Business Meeting of December 19th, 1891, and read a letter from Mr. H. W. Clarke, Active Member, Syracuse, New York, expressing the opinion that the amendment added unnecessary complications in connection with the making of nominations.

On motion of Mr. H. W. Spangler, seconded by Mr. Howard Murphy, the amendment was amended so as to provide that the Nominating Committee, to consist of five members, only one of whom may be a member of the Board of Directors, shall supply only such vacancies as may exist in the ticket.

On motion of Mr. H. W. Spangler, seconded by Mr. Coleman Sellers, Jr., it was ordered that when in the opinion of the Board of Directors it becomes necessary to amend the Constitution and By-Laws, the President shall appoint a committee for the purpose.

The resignations of Messrs. T. C. Clarke, C. H. Middleton, Jr., O. B. Colton, Samuel Tobias Wagner, Geo. W. Hewitt, R. R. Bridgers, Jr., and Burr K. Field from Active Membership, were accepted.

The resignations of Messrs. Jas. F. Wood, Horace See, W. S. Chaplin and S. B. Whiting were read for the first time, and on motion of Mr. Howard Murphy, referred to the Membership Committee, with the understanding that delay in their acceptance should involve no additional dues.

The resignation of Mr. Jesse Garrett was read for the first time and action thereon was deferred.

Mr. Carl Hering presented a communication setting forth the desirability of providing a large building for the joint use of the various engineering and other technical societies in this city, and moved the appointment of a Committee of five to confer with these societies and to discuss the advisability of a plan of this nature. Action upon this motion was deferred under the rules.

Mr. G. T. Gwilliam, Teller, suggested that in future the voting tickets should contain a statement of the number of negative votes necessary to exclude a member.

Mr. Rudolph Hering presented the following preamble and resolution :

"WHEREAS, In the opinion of the Club, it is desirable that it should be represented in the move now being made to obtain surveys and a report upon the proposed ship canal across the State of New Jersey ;

"Be it therefore *Resolved*,

"That the Committee on Land-locked Navigation be requested and empowered to appoint a sub-committee from its membership to co-operate with similar committees of the Philadelphia Trades' League and of the New York Board of Trade and Transportation, to further the project."

Action upon this motion was deferred, as required by the By-Laws.

The Secretary read a letter from Mr. Richard B. Osborne, transmitting a lithographic view of the Delaware River front of Philadelphia in 1761.

The Secretary announced the deaths of Messrs. R. H. Lee and Edward Nichols, Active Members of the Club.

On motion of Mr. T. Carpenter Smith, a vote of thanks was passed to A. J. Rudderow, Esq., for his services in connection with the incorporation of the Club.

After adjournment, Mr. James Christie, President-elect, briefly addressed the members present, urging united effort on their part in behalf of the Club during his administration.

FEBRUARY 6, 1892.—Business Meeting.—President James Christie in the chair. About fifty members present.

In the absence of the Secretary, owing to illness, the chair requested Mr. Wilfred Lewis to act as Secretary *pro tem.*

The Tellers reported that 83 votes had been cast, of which 77 were in favor of the Amendment to Art. III, Section 2, of the By-Laws, and 6 against it, and the Chair declared the Amendment adopted. It provides for the appointment of a Nominating Committee to supply deficiencies in the ticket for the annual election of officers.

The appointment of a committee in aid of a ship canal across New Jersey to co-operate with similar committees of the Philadelphia Trades' League and of the New York Board of Trade and Transportation, was, on motion of Mr. Murphy, referred to the Chair with power to act. The President then announced that at the suggestion of Captain McCorkle, Chairman of the Committee on Land-locked Navigation, he would appoint Messrs. Hering, Crowell, Haupt and Swift, as the sub-committee.

A letter from Mr. Chas. E. Billin was read, suggesting that a committee of three be appointed by the President to prepare memorials on the deaths of Messrs. R. H. Lee and Edward Nichols, and that the same be published in the Proceedings of the Club.

After some discussion by Mr. Murphy on the general policy of the Club in such cases, it was moved by Mr. d'Invilliers that the Secretary be directed to prepare suitable memorials to be spread upon the minutes of the Club, and the resolution was adopted.

On motion of Mr. Falkenau, the consideration of the proposition for an Engineering building was deferred on account of the absence of its originator, Mr. Carl Hering.

On motion of Mr. Murphy, the resignations presented were referred to the Committee on Membership, to be brought up at a subsequent meeting.

Referring to the unfortunate result of a recent election, Professor Haupt claimed to be credibly informed that the failure of one of our oldest and most eminent Civil Engineers to receive the unanimous vote necessary to election as an honorary member was due to an objection held by one or more members against having an honorary class of membership, and in view of that admission, he desired to enter his formal protest against such action for such reason, as unconstitutional.

After some discussion by Messrs. Murphy, Haupt, Falkenau and d'Invilliers, it was resolved, on motion of the latter, that the matter be referred to the Membership Committee.

On motion of Mr. Murphy, it was a'so resolved that the Committee be requested to ascertain from the Tellers the number of negative votes cast and report to the Club.

Mr. J. J. McKee exhibited a series of lantern slides, illustrating the progress of the work on the East Jersey Water Company's pipe line, and was warmly applauded.

On motion of Professor Haupt, the privilege and freedom of the Club House was extended to Mr. Clemens Herschel, the engineer in charge, who replied to several questions concerning engineering features of the work; and on motion of Mr. Murphy the thanks of the Club were voted to Messrs. McKee and Herschel for their interesting remarks.

February 20, 1892.—Business Meeting.—Past President Henry G. Morris in the chair. About 40 members present.

A note from President Christie, regretting his inability to be present on account of illness, was read by the Secretary *pro tem.*

A communication from Prof. H. W. Spangler was presented, objecting to the approval of the minutes of the last meeting, and making the point of order that, as the resolutions offered by Mr. d'Invilliers and Mr. Murphy on page 4 of the Record, bore upon business not stated in the notice for the meeting, they were in violation of Art. I, Section 2 of the By-Laws, and that the action taken, or any other action based thereon, should be declared unconstitutional.

The Chair decided the point of order well taken and declared the action referred to as unconstitutional.

On motion of Mr. Kneass, the minutes were approved as corrected.

After some discussion on the advantages of a large building for the joint use of the various engineering and technical societies of Philadelphia, it was resolved, on motion of Mr. Carl Hering, that a committee of five be appointed to confer with other societies on the advisability of erecting a large building for their joint use.

The Tellers of Election reported through their Chairman, Mr. A. Falkenau, that 106 ballots had been cast and the following candidates were elected:

Messrs. D. P. Bruner, Walter C. Kerr, Paul A. N. Winand, Joseph C. Wagner, Henry L. Butler, Thomas Earle, Herbert P. White, Thomas Willis Fleming.

The resignations of Messrs. Horace See and James T. Wood were read and accepted.

Circulars from the Executive Committee of the World's Columbian Exposition

were read, and, on motion of Mr. Murphy, the matter was referred to the Board of Directors.

A memorial of R. H. Lee, which had been prepared by Mr. Trautwine, was presented, and on motion of Dr. Chance it was directed that same be incorporated in the minutes and printed in the Proceedings.

A memorial of Edward Nichols was reported to be in progress.

The following report was presented:

The Club Committee beg leave to report that they have held a number of meetings and considered various matters, upon which they may report to the Club in the future.

For the present we would recommend that we be authorized to obtain subscriptions for a billiard table, to be placed in the third-story front room, without making any alterations other than the introduction of a proper chandelier. A new and first-class billiard table, with all appurtenances, will cost $250; and a proper chandelier, put in place, $11, making $261 the total cost.

We will also recommend that the Secretary be directed to subscribe for the Club, to *Puck*, *Judge* and *Life*, for our reading-room.

Respectfully,

HOWARD MURPHY, *Chairman Club Committee.*

Mr. A. Saunders Morris read his paper on the Limitations of Electric Power Transmission, which was discussed by Mr. Carl Hering, and Mr. Morris replied to a number of questions raised.

Messrs. A. Marichal and J. C. Trautwine, Jr., presented in abstract their translation of the second portion of M. Bazin's Weir Experiments, and a letter was read from Mr. Robert A. Cummings, expressing his appreciation of the labors of the translators in bringing these experiments before a larger audience of engineers.

MARCH 5, 1892.—Business Meeting.—President James Christie in the chair. 55 members and 5 visitors present.

A memorial of Mr. Edward Nichols was presented and ordered to be printed.

The Secretary announced the death of Mr. H. Wadsworth Clarke, of Syracuse, New York, who was elected a member of the Club April 7, 1883, and died February 23, 1892.

Mr. Howard Murphy moved that the Tellers of Election be required to inform any member of the Club desiring such information as to the details of the vote cast at recent and all future elections.

After some discussion the matter was laid on the table.

On motion of Mr. Murphy, the recommendations of the Club Committee, contained in their report of February 20th, were adopted.

The Secretary presented a letter from Mr. O. Chanute, stating that he had been requested, as representing the association of various engineering societies in this country, to extend to their members a cordial invitation to attend the Fifth International Congress for Internal Navigation, which is to be held at Paris, France, beginning July 21, 1892, and to continue for ten days.

Mr. Barton H. Coffey presented a paper on the Cost of Producing Power in the Internal Combustion Engine.

Mr. Carl Hering gave some items of cost of the transmission of power from Niagara Falls to Buffalo. The units intended to be used are 5,000 horse-power. The

dynamos are to be coupled directly to the turbine by vertical shafts. 600 to 700 volts at the dynamo is to be transformed to 25,000 volts on the line. Three phase dynamos are to be used, making 250 revolutions and supplying 2,000 ampères. The cost of the whole plant per unit of 5,000 horse-power is to be $180,000, or $36 per horse-power. This estimate includes generator, line and transformers at each end, line cost alone being $20,000. At present the cost of dynamos varies from $50 to $75 per horse-power. The total efficiency of the plant is to be 84 per cent. from the shaft of the turbine to the secondary terminals at Buffalo, the dynamo alone giving an efficiency of 96 per cent.

Mr. Wilfred Lewis introduced Mr. J. Bogart, Engineer of the Construction Company, who stated that the Oerlikon Company's bid is about as Mr. Hering has given it, but the problem that interests us is rather what will steam-power cost under the most favorable conditions, with coal of a given price, or for how much could a company put in a steam plant and sell to customers power? He also stated that he had received two estimates as to the cost of power under these conditions, and that the problem is by no means an easy one is shown by the fact that the larger of these estimates is about two and one-half times the smaller. The solution must not be complicated by other questions, such as the use of steam for heating, or other purposes, and this makes it a particularly difficult one to handle.

Mr. Murphy stated that his recollection was that the cost of pumping water at the eight steam stations in Philadelphia was in the neighborhood of $8 per million gallons. pumped 100 feet, while at Fairmount the cost was $2.

Mr. Smith: The marine engine seems to be about the nearest to the solution of the problem.

Mr. Hering: I would like to ask Mr. Bogart what the cost of power will be at Niagara.

Mr. Bogart: We cannot tell, because the work is not done. The tunnel must be lined with brick, and the shafts for the turbine are not finished. We propose carrying a notch instead of several shafts for our power, but we are ready to sell power in large quantities at $10 per horse-power per annum at Niagara.

Mr. Salom: At Lockport Mr. E. H. Cowles told me that their power did not cost $3 per annum, and I would like to ask Mr. Bogart what they propose to do with the power that they develop, as five persons per horse-power is about the maximum in the most thickly-settled manufacturing districts.

Mr. Bogart: The plant, as now under way, is capable of developing 100,000 horse-power. It is proposed to use this first at Niagara Falls, or at the present station by giving power to manufacturers for coming there. Many manufacturing industries take much more horse-power than that stated by Mr. Salom—wood-pulp mills, for instance—and a 3,000 horse-power plant is being put in by one company, and a second plant is under consideration. It is in the minds of the Company, also, to transmit power to Buffalo, which is a city of a large number of small power establishments. The turbines are to be about 120 feet below the surface, leaving 20 feet to spare. The water that can be taken by the tunnel will take a film of 1¾ inches off the Falls, the average depth being about 6 feet, as near as we can judge.

Dr. Chance: Has any arrangement been made to put in impact wheels?

Mr. Bogart: Careful study has been made of this subject with the Pelton Company, but the conditions do not seem to be favorable.

Mr. Lesley: The location of Buffalo makes it one of the greatest inland shipping

ports in the United States, and the transmission of power in large quantities at cheap rates should make it one of the largest manufacturing centers also.

Mr. Bogart: The Company has bought the right of way for another tunnel of the same size.

Mr. Roney: I should like to ask Mr. Bogart as to the probabilities of trouble from ice.

Mr. Bogart: We do not anticipate any trouble in the tunnel, and any ice that may form above will be carried down independently in a shaft put in purposely for an ice-shaft.

Mr. Salom: I have no fear but that there will be users for the power. It requires 24 horse-power per day to produce one pound of aluminum, and a few tons will utilize the entire plant as at present under way.

Mr. Murphy: Will Mr. Bogart give us an idea of a section of the tunnel?

Mr. Bogart: The area is that of a circle of twenty-five feet in diameter. It has, however, a circular top and a very shallow invert. It is through rock and lined with brick masonry.

Mr. Wilfred Lewis read for Mr. Francis a communication describing a peculiar accident to a Buckeye engine.

The Secretary presented a cut showing the Carruthers Rail Joint. This joint is a method of supporting the ends of rails by wedges working in slots, in that part of fish-plate carried below the sole of rail. The bottom sides of the slots are inclined planes, up which the wedges travel to the sole of the rail, to which they are kept tight by keys, driven vertically between them. The keys passing between the wedges, striking a shoulder, become turned and fixed.

March 19, 1892.—Regular Meeting.—President James Christie in the chair. About 40 members present.

The Publication Committee announced that they had directed the Secretary to notify the members of the Club that back numbers of the Proceedings could be obtained at a uniform rate of 50 cents per number by members, and that the Publication Committee would be glad to correspond with any members of the Club having duplicates of any of the back numbers, and, except in such cases where full sets would be broken, they would be glad to exchange for any number in the possession of the members.

Mr. Arthur Falkenau presented a paper on the Cost of Power in Mexico and our Western Mining Regions.

Mr. Paul A. N. Winand presented some figures as to the cost of power in using internal combustion engines.

Mr. Strong: One of the most interesting papers I have read on the subject of the cost of power was by Sir William Thompson, in 1881. In this paper the sources of power were divided into four, which were wind-power, falling water, tidal energy and coal. The first two of these are due directly to the sun's heat, and, what might at first appear strange, the first of these has had more to do with the comfort and progress of this world than any other power, and it is probable that the time will come again when wind-power, in connection with some such apparatus as the storage battery, will again do the work of the world.

Tidal energy and water-power he regarded as insignificant. The burning of coal he also considered as one of the sources of power which was derived from the sun's energy.

Prof. Elihu Thomson read a paper in Boston last week, and said that the hope of the electrical engineer was in the steam engine, or that the mechanical engineer would produce cheaper power than by the steam or gas engine.

Clark says that it is possible to use 40 per cent. of the energy in the coal through the gas engine, while the best steam engine only uses 13 to 14 per cent.

The difficulty in the way of introducing producer plants and gas engines is the first cost and the difficulty of starting the engines, but this latter difficulty will probably be soon overcome, and the gas engine will then supersede the steam engine in many cases. We have been engaged in designing an engine which is to make a horse-power on 13 pounds of water, and in the boiler we expect to carry 180 pounds pressure, allowing the gas to escape at 250 degrees, and evaporating 12 pounds of water to a pound of coal.

The Secretary read for Mr. Alan N. Lukens a paper on Cost of Errors in Transmission of Power, in which he cited numerous instances of erroneous transmission which had come under his observation. In summing up the evils of erroneous transmission, he said there were to be noticed, first, the alignment of the shafting, the spacing of hangers and pulleys; second, the adjustment of the bearings, the size of the pulleys and the tension of belts. All these add to the power required, and therefore cost money, as well as requiring extra time and labor, to keep them in anything like good order, and time is money, as everyone knows.

Mr. Strong: Many think that the locomotive is an uneconomical steam engine, but it really compares very favorably with the general run of automatic engines to be found. A few years ago a test was made on the Lehigh Valley Railroad, under unfavorable circumstances, on a boiler having 1,848 square feet of heating surface. 900 horse-power was developed, eight pounds of water being obtained per pound of coal, and in another boiler which was tested, 28 pounds of water to the horse-power were used, while in the one first spoken of only 20 pounds were used.

Mr. Coffey: I hardly think 22 feet can be taken as a fair average of the amount of gas used per horse-power. I find the diameter has a great effect on economy. Small cylinders run up to 40 cubic feet; the last test cited by Mr. Winand with 17-inch cylinders, using .88 pounds per horse-power, or .85, omitting the amount of coal used for making steam to use with the producer. The exhaust gas should be used for this purpose, and this amount of coal saved. I do not think the radiation makes the difference between gas and steam engines, but the getting rid of the latent heat. The loss in the jackets varies from 25 to 50 per cent. I doubt whether 12 pounds of water can be had per pound of coal.

Mr. Strong: The Boston Sewage Pumping Plant are getting about 12 pounds of water per pound of coal, using two sets of boilers. In the locomotive we get 9 pounds of water, while we were making 1 horse-power for each 2 square feet of grate.

Mr. Spangler said that he doubted very much whether the boiler had been made which would average 12 pounds of water per pound of coal. Short tests were of course entirely unreliable, and, that the report of any test showing 12 pounds of water should be believed, the data should be put in such shape that any intelligent engineer could readily understand all the details of the method of making the test, satisfying himself as to the probability and liability of error in the test as conducted.

April 2, 1892.—Regular Meeting.—President James Christie in the chair; 38 members present.

The tellers reported that the following gentlemen had been elected to Active Membership: Messrs. Henrik V. Loss, F. V. Hetzel, Clayton W. Pike, H. M. Montgomery, C. O. C. Billberg, Chas. W. Close.

Mr. W. S. Auchincloss read a paper on Yearly Tides.

In this paper the author stated that he proposed to show that confined bodies of fresh water are subject to yearly tides of greater or less magnitude, depending upon the nature of the basin or upon the strata to which they are confined, and upon the effect of evaporation if in an open basin.

This paper was discussed by Messrs. Codman, W. Lewis and H. M. Chance, and the author.

Mr. Jacques W. Redway presented a paper on The Influence of Rainfall on Commercial Development—A Study of the Arid Region.

The Secretary presented for Mr. George A. Bullock a large wall map, showing the street-paving of Philadelphia, which was accepted with thanks.

A Note on Engineering Civil Service, by Mr. Gratz Mordecai, was presented by the Secretary.

The Secretary also presented from Mr. Robert A. Cummings, a letter on the same subject, explaining the method of determining the necessity and placing the contracts for any work which may be desired.

April 16, 1892.—Regular Meeting.—President James Christie in the Chair; about 75 persons present.

The meeting was devoted to an informal discussion of the Trolley system, of which the following is an abstract:

Mr. Carl Hering: The trolley system, electrically and financially, is a perfect success. There are at present over 3,000 miles of electric railways in regular daily operation in the United States.

With the exception of the cable, the trolley offers the cheapest method of street-car propulsion where the traffic is large and the grades are steep.

A battery that would stand the severe demands upon it would render the storage battery system entirely satisfactory. As it now stands, this system is more expensive than the trolley. I know of but one existing conduit line in regular operation, viz., that at Buda-Pesth, in Hungary. This works satisfactorily. The ground return renders the trolley system a huge lightning-rod, with great danger of fire in case of the crossing of wires. Where neither wire is grounded, two contacts are necessary to cause an accident, but where either wire is grounded, one contact suffices.

The lives of persons using telephones are not in danger from the crossing of the telephone wire with the trolley wire.

I know of no authentic record of loss of life through taking the shock from a trolley wire.

The number of deaths in Boston is said to have increased 100 per cent. since the introduction of the trolley system there, but the additional cases were caused by run-overs and similar accidents, not by electric shock from the wires. There is, however, great danger of fire.

Dr. H. M. Chance: How many deaths occur from the running of the fast trolley system in Pittsburgh?

The Secretary: If I may be allowed for once to transgress the By-Laws, I would say that I have heard it stated that little, if any, loss of life has occurred there from

that cause. Each car, I am told, carries a sort of rubber apron in front, in which those citizens who may carelessly place themselves in the way of the rapidly moving car are harmlessly tossed into the air and then released after a short ride. How they enjoy this treatment was not stated.

Mr. Henry G. Morris: An electric light lineman was killed on a pole in Boston, and it was claimed by the electric light people that there was no current in their wire and that his death resulted from the crossing of theirs with the trolley wire.

Mr. H. C. Lüders: Would not a current of 500 volts passing through a No. 14 telephone wire fuse the wire and thus prevent the current from reaching the person using the telephone?

Mr. Morris: That would depend not only upon the voltage (electro-motive force), but conjointly upon the amount of the current in ampères.

Mr. F. R. Ford: Dr. Massey finds that the resistance of the human body is 1,000 ohms, and that a half ampère (which is equivalent to 500 volts passing through a resistance of 1,000 ohms) will not kill a human being. An experiment has been tried upon a worn-out car-horse. One of the wires was wrapped several times around the body of the horse and the other was attached to an iron plate upon which the horse stood. 510 volts were then passed through the wire. The horse jumped, but after sustaining the current for 15 seconds, his condition seemed, if anything, slightly improved.

A voltage of 500 is a compromise between requirements of safety on the one hand, and the expense of wiring on the other.

Professor L. F. Rondinella: Professor Houston stated at the Franklin Institute that under certain circumstances he would not mind taking a current of over 1,000 volts, whereas, under other circumstances, 5 volts would be unsafe. A given current for instance, would be much more dangerous if taken in one hand and passed out at the other, so as to traverse the vital organs, than if taken in one arm and passed out through the leg on the same side. A current of ten volts might be fatal, if applied at the back of the neck.

Mr. Carl Hering: As to the horse mentioned by Mr. Ford, instead of winding the wire about the body, where the hair would act as an insulator, it should have been applied through the hoofs, as would probably be the case with horses on the street. If one's hands are dry, there is less danger than if they are moist. A current taken through water, especially if it contains soda, would be working under conditions favorable to accident. The horse-shoe nailed to the moist hoof makes an excellent conductor, and this is, no doubt, why so many horses are killed. A current of 20 volts will make them jump badly.

Mr. Wm. Wharton, Jr.: All animals differ in their susceptibility to electric shock. The human body offers a higher resistance than that of the horse.

By increasing the size of the conductor we may reduce the tension, and thus make the trolley system as safe as the storage system.

Mr. C. H. Roney: On the experimental road on Ridge Avenue it was found that the cost of a conduit system was higher than that of the trolley; but, on the other hand, the conduit system is much more convenient. It causes no obstruction of the street and there is no possibility of falling wires with their attendant accidents.

The principal objections to the trolley system are the danger of accident through contact with electric light wires, and the obstruction to the fire department in case of fire. A minor objection is the unsightliness of the system.

Mr. Wharton: Inasmuch as the arc light wires are the most dangerous, it is they and not the traction wires that should be put under ground. The trolley system is often charged with accidents which occur through contact with electric light wires. A year or two ago, two men were carrying from a building a show-case with metal frames, and an exposed arc-light wire, hanging down, touched the frame and one of the men was killed. It would be as just to argue from this that the carrying of show-cases with metal frames is a dangerous practice.

Mr. Wm. M. Kerr: The trolley wires are necessarily naked, whereas the arc-light wires are insulated.

Mr. Wharton: The insulated wires are all right until the insulating material is rubbed away, and this is very easily done.

Mr. H. B. Hirsh: Is the conduit system in Chicago the same as that used at Buda-Pesth?

Mr. F. R. Ford: I believe that in Chicago is of the Love system, and is not yet in successful operation. Of some 400 electric roads in the country that in Camden is the worst. It uses the old Daft system, with two overhead wires, carrying a current of 200 volts. The line construction is abominable and would not be tolerated elsewhere.

As to the cost:—a road with wooden poles, with the rails bounded for the return circuit and with construction otherwise of the cheapest, a road may be built for $1,000 a mile; while with iron poles, 125 feet apart on each side of the street, with span wire crossing at each pair of poles, and with feeder wires on one set of poles, etc., the cost may reach $5,000 per mile. For feeder wires underground in wooden troughs, we must add $3,000 per mile of single track, and this will give the most perfect electric railway now known. I understand that the Traction Company is considering the use of a special overhead construction on its Spruce Street line, having a single line of poles on the curb, with arms extending to the middle of the street. At every other pole, or 250 feet apart, an arc-lamp is to be mounted for lighting the street. This construction is no more unsightly than the arc-light system now in use upon Green Street, and has only one additional wire, viz., the trolley wire in the middle of the street. The electric light system will use a separate current.

Mr. Carl Hering: I think the companies would object to the expense for the heavy wire required to reduce the voltage below 500, as suggested by Mr. Wharton. A very serious objection to the trolley system is that it is liable to start several fires in a house at one time. This danger is greater in Philadelphia where the ordinances require no guard wires, than in places like Boston where two guard wires are required.

Mr. Wharton: Such guard wires will, however, be required here also before long. The ordinances now require that the Director of Public Safety shall prescribe the use of such protective appliances as he may see fit. Besides, it is to the interest of the company itself to erect the best possible structure.

Mr. W. C. L. Eglen (visitor): No company has adopted means to avoid interference with the ground return of telephone wires. A wholly metallic circuit, of course, requires twice as much copper wire as the ground-return system, but it is entirely free from danger of fire. The insurance companies have objected to the use of the ground-return system.

Dr. H. M. Chance: Horses and mules have been disabled and often killed, I believe, by a current of 200 volts. In a mine the roadway is wet and the animals often have to travel through water or mud up to their fetlocks. This, of course, makes an ex-

cellent contact with the most vulnerable parts of their bodies. In streets the current has to find its way through the comparatively nonconducting hoofs and hair.

Another serious objection to the trolley system is that in the future improved systems will certainly be devised, but those companies that have established their trolley plant will not be willing to adopt these systems.

Mr. Henry G. Morris. At present, the cost of running by the trolley system is 4 cents per car-mile less than with horse-power. The storage battery is at least as cheap as horse-power.

Mr. T. Carpenter Smith: The question of danger to life depends entirely upon how the current is taken. I have taken 1,000 volts of alternating current dozens of times, and 1,500 volts of direct current, in the most dangerous way, but that I am here this evening is due to the fact that my hands were then dusty. It has been stated that the resistance of the human body is about 1,000 ohms, but the testimony in the Kemmler case showed that in this respect no two men are alike. There is no standard. As to the quantity that may be taken, I would not be willing to risk half an ampère. The testimony showed that under certain circumstances one-tenth of an ampère may be fatal. We must consider the voltage and the quantity conjointly. Arc-light circuits have a high voltage. They are dangerous to life, but not liable to cause fires. A current of 10 ampères is equal to 65 horse-power. A trolley system of 500 volts has unlimited quantity behind them.

The Camden road would be much better with a ground-return and 500 volts.

The burying of the feeder wires is of no account. They can be insulated when on poles. What is wanted to secure safety is the burial of the trolley wire. Two or three years ago Albany had 55 fires in one night. Owing to sleet the bare wires of the fire-alarm system fell upon the trolley wires and the fire system was burned out.

Automatic protectors are all right where there is a good rush of current, but they will not protect in cases where there is only a slight leak. In every telephone there is a small coil of very fine wire. No protective device is successful in protecting this coil, and if it is highly heated it may set the building on fire

A current of 500 volts will ordinarily not kill, but it will burn terribly. Some years ago, a workman having hold of a rheostat wheel touched a copper bar in an electric light system with only 220 volts. He was burned as badly as if his arm had been held against a red-hot plate. I believe he never recovered the use of the arm. 500 volts are fatal to horses and mules every time. In New York I have seen horses knocked down by trying to cross a street in which such a current was grounded.

If one-tenth of the amount spent upon the trolley system had been expended on any other, we should have had far better systems long ago.

It has been claimed that the Traction Company would not put up a cheap structure, or use poor devices. The answer to this may be seen in their cable system here. They have given us the cheapest possible system, and to Pittsburgh and New York the best possible. They will never adopt a better system unless they are compelled to do so, and the more they are made to spend now upon their trolley system, the tighter they will hold on to it.

For the large number of cars of the Traction Company, many wires will be needed, and they will have to be loaded up to the muzzle. I believe that the storage system, properly developed, would be found cheaper than the trolley. All the experiments with storage batteries have been made upon a small scale and upon the poorest part of the road. Another difficulty is that the engineer in charge of a storage line is hampered by the conflicting private interests of inventors.

Mr. Herman S. Hering: The storage battery is now being tried in Washington on a large scale, up to 700 horse-power, by the Metropolitan Railroad. They have no battery, however, as there is none upon the market.

Mr. Henry G. Morris: I beg to say that I am interested in one which is very much on the market. Some eight or ten storage battery cars were running in New York a year or two ago. There was a 12-mile circuit with 5 per cent. grades from Eighty-fifth Street to the Post Office and the Battery. On the return trip the batteries were working under the worst possible conditions. The running of the line was stopped only by adverse litigation.

Mr. Carl Hering: I would refer those interested to the report of the operation of the electric roads in Birmingham, England. In that city the cable system, electric and horse roads were tried, and accurate records of their operation were kept. The last United States census also contains valuable information on this subject.

There are two principal objections to the conduit system. The first is the cost. The system in Buda-Pesth cost $20,000 per mile, and would have cost $35,000 here. Once down, however, the cost of maintenance is less than that of other systems. The other objection is that the conduit fills with water, but this may, of course, be drained away.

Mr. Howard Murphy: Can we not protect buildings having phone wires, even if these should come in contact with the trolley wire? Could not the phone wire be fully insulated?

Mr. T. Carpenter Smith: The trouble is in the telephone itself. It has been suggested that the telephone box might be made of metal to avoid danger from fire, but this would involve danger of shock to the operator.

Mr. Carl Hering: Among the systems tried at Birmingham, the electric accumulator system is the cheapest under ordinary circumstances, and horse cars are the dearest. The cable is the cheapest for heavy traffic on heavy grades.

Dr. H. M. Chance: In New York, where the horse-car lines have to compete to some extent with the steam elevated roads, the horse-cars make 7 miles per hour, which is about the limit of safe running. Here they make $2\frac{1}{2}$, but this is not on account of the slowness of Philadelphia horses. According to statements made by mechanical engineers, the steam dummy is the cheapest system of street-car propulsion.

Prof. William S. Aldrich (visitor): In Chicago the overhead steam roads can hardly keep up in speed with the cable surface roads. The great advantage of the cable is that the car, after stopping, very soon picks up speed—in Philadelphia, indeed, almost *too* quickly. A steam train cannot do this. The cable gives the most rapid surface transit possible. After it comes steam, and then electricity. The storage battery is best on crowded streets, and the trolley on long stretches of open streets and park. It can pick up speed more quickly than the storage battery car.

May 7, 1892.—Business Meeting.—Mr. James Christie, President, in the chair; about 50 persons present.

The resignation of Mr. W. S. Chaplin, received in December last, and those of Messrs. A. S. Coffin, J. H. Skinker, J. B. Nau, Frank Lyman, Robert E. Pettit, A. Millet, S. B. Whiting and Geo. R. Henderson, received in January, were reported back by the Board of Directors, with a recommendation that they be accepted, and on motion of Mr. Howard Murphy, they were accepted, to take effect at their respective dates.

The Secretary presented his resignation of office, and on motion of Mr. Henry G. Morris the matter was referred to the Board of Directors with a request to report at the next meeting.

The Secretary presented a communication from Mr. Octave Chanute, President of the General Committee of Engineering Societies, Columbian Exposition, Chicago, enclosing copy of a letter sent by the Executive Committee to Mr. John W. Cloud, the Club's representative in Chicago, notifying him of a meeting of delegates comprising the General Committee of Engineering Societies, at Chicago, on May 4th.

The discussion on the Trolley System, continued from the meeting of April 16th, was resumed.

Mr. Carl Hering presented the following statistics:

It is only seven years since the first electric railway was put into commercial operation in the United States. On January 1st, 1888, there were in operation only 48 miles of electric roads, while in 1891 there were 2,893. From the U. S. Census of 1890 we learn that there were then 8,123 miles of street railway tracks in the United States, carrying 2,023,010,202 passengers annually, or 50 times the population, or more than the population of the globe, or almost five times the number carried on all the interuban steam railroads. 1,500,000 passengers are said to be carried daily by all the electrical roads, the number of car-miles being about 400,000 per day. The last two figures are, however, probably too high.

In September, 1891, the subdivision of the varions street railways was as follows: 5,442 miles operated by animal-power, 3,000 by electricity, 1,918 by steam and 660 by cable. 1,003 roads use animals, 412 electricity and 54 cable. The diminution in the number of horses in one year was 28,681. England has only 29 miles of electric railroads.

The number of passengers carried per year in Philadelphia is given as about 150,000,000 or over 100 rides per inhabitant, about the same ratio as in New York. The elevated roads in New York carried 400,000,000 passengers. Philadelphia has 510 miles of traek, or, with the exception of Chicago, which has 452 miles, it has almost twice as many miles as any other city in the country.

Other figures were given showing the cost of construction and operation of electric roads, their comparison with other systems in the United States, the distribution of the traffic, etc.

Mr. P. G. Salom: The uncertain element in a comparison of the merits of the trolley and of the storage battery is the duration of the latter. If this could be certainly known, there would be no difficulty in ascertaining definitely the relative cost of the two systems. The problem of the manipulation of the battery is a mere matter of executive management, and its cost, while relatively important on a small plant, would be trifling in a large system. Here again the storage battery suffers from the fact that the experiments upon it have been heretofore confined to a small scale. As much as 6,000 car-miles have been run with one set of batteries and it has been found that under the worst possible conditions one car-mile is equivalent to $1\frac{1}{2}$ electric horse-power hours, so that one set of 1,108 accumulators will furnish 9,000 horse-power hours, showing that $\frac{9,000}{54} = 166$ discharges are necessary for this work. The cost for power may be assumed at 2 cents per horse-power hour, or 3 cents per car-mile.

The term "cost per car-mile" is, however, a very indeterminate one, for that cost depends greatly upon the conditions under which the road is working, as to grades, character of track, amount of traffic, etc.

Mr. F. R. Ford: An average of many roads using the trolley system gives 13 or 14 cents as the cost per car-mile, with 7 cents in one particular case.

Mr. Salom: I repeat that estimates of cost per car-mile are valueless unless it is known what items enter into the estimate. The West End Road, of Boston, the best trolley system we have, reports about 20 to 21 cents per car-mile, but this embraces many items not usually included in that cost. In the trolley system the duty varies greatly and suddenly, while in the storage battery system the duty is constant. A comparison of results obtained at Birmingham, England, shows that horse-cars were operated at about 15.7 cents per car-mile, and a storage battery system at $14\frac{3}{4}$ cents per car-mile.

The difference of 4 cents per car-mile in favor of the trolley system, as compared with the storage battery as at present developed, makes a difference of $3,000,000 per year, on a system operating 2,000 cars, averaging 100 miles per day each, and the difference would be still greater with a complete system in operation.

As compared with horse-power, the storage battery system shows a great reduction in the space required. Allowing 12 horses for each car, the space occupied for stabling would be 12 times that required for the accommodation of a storage plant.

Mr. Carl Hering: Mr. Salom is quite right in contending that the cost per car-mile should state what items are included, but as to the difference between two roads in the matter of grades, it must be borne in mind that the up-grades become down-grades on the return trip. The high figures given for the cost per car-mile on the West End Road include all the operating expenses, even damages for accidents.

Erroneous results may be reached by taking laboratory experiments on the discharge of accumulators as indicating their life in actual practice on the road. The strains due to stoppages and startings may be reproduced in the laboratory test, but the agitation to which the batteries are subjected in running wears away the materials of the battery by a sort of sand-blast action due to the hurling about of the detached particles in the battery, and this it would be difficult to reproduce in the laboratory.

The statistics which I have quoted from the United States Census may be found in the *Street Railway Journal* for December, and those for the Birmingham roads in the same Journal for January last.

Mr. C. Henry Roney read a paper descriptive of the experimental electric conduit system constructed and operated on Ridge Avenue, Philadelphia, in 1885 and 1886.

A quarter of a mile was laid in the fall of 1885, and a car was run at times during the winter. The conduit had been badly laid by inexperienced labor, and was sometimes full of slush and snow. In the spring of 1886, the conduit was relaid in a more substantial manner and another quarter mile added, and the road, as thus extended, was run successfully as an experiment until the autumn of 1887. The conduit was of wood and was laid between the rails. The maximum grade was about 5 per cent., and this was on a curve of 30 feet radius. The car, with the motor, weighed about 1,800 pounds and carried from 30 to 40 passengers. The power station was located at the south end of the conduit, at Susquehanna Avenue, and the engine was rated at 20 horse-power. The station dynamo was also of 20 horse-power and made 1,100 revolutions per minute, giving a direct metallic return current of 80 ampères and a potential of 80 volts. The estimated capacity was two loaded cars. The conduit was 7 inches deep by 4 inches wide, and the conductor was a copper strip 1 inch wide by $\frac{1}{8}$ inch thick. To the conductor a channel iron 1 inch wide was fastened by screws, to prevent the wear of the conductor by the brushes or contact springs of the

current collectors, which moved under the groove of the channel iron and were guided by it. The copper conductors were insulated from the conduit by red fibre, which absorbed moisture and thus rendered the insulation imperfect. The motor was an old arc-light dynamo of the Siemens drum-armature type, re-wound to suit, fields compound (shunt and series), the series coils being cut out after fairly getting under way. The motor was of 15 horse-power and made 900 revolutions per minute. The maximum speed of the car was about 10 miles per hour, empty, and 8 miles, loaded. The loss from the defective insulation of the red fibre sometimes amounted to 50 ampères on starting in stormy weather, but it quickly ceased, and, if the car was kept running constantly, the loss seldom exceeded 5 ampères. The electric cars could be run only between the regular trips of the horse-cars. I am told that the same system, but without any conduit and with exposed conductors, has been used successfully for five years in a Pennsylvania anthracite mine, as well as in mines in the Hocking Valley, Ohio, and in Colorado. I have not been able to learn that electric storms have interfered with the operation of the system.

The cars were brilliantly lighted by incandescent lamps.

The conduit system shares with the cable system the three objections of high first cost, the slot in the conduit (which, however, need not be more than from $\frac{1}{4}$ to $\frac{3}{8}$ of an inch in the electric conduit system), and the dependence of the entire system upon the supply of power from the central station. The latter objection is shared also by the trolley system.

Mr. Carl Hering sketched upon the board a cross-section of the conduit used in Buda-Pesth. The conduit is of concrete, with cast-iron frames every three or four feet. The road is ten or fifteen miles long, and is the only electric conduit road now in successful commercial operation on a large scale.

It is stated that an increase from six miles per hour (the usual speed of horse cars) to nine miles per hour doubles the residence area of a city, allowing to each person a given time for daily rides.

Mr. Ford: Mr. Salom has stated that the life of an accumulator is about 6,000 car-miles. Will he state what it costs at the end of that time to replace the plates?

Mr. Salom: As stated in the October number of our Proceedings, about $2.50 per element, or say $250 per car, or 4 cents per car-mile.

As to the comparison between laboratory tests of storage batteries and the test in actual practice, I will say that the latter test is more severe than it ought to be, and more severe than it would be if the storage system had been exploited as industriously as the trolley system. There should be a resistance placed between the battery and the motor, to avoid the severe strain of starting.

Mr. T. Carpenter Smith: The cost per car-mile, as given in the figures of the West End Road, in Boston, may be relied upon as entirely correct. In Massachusetts, the electric companies are required to conform to a certain system fixed by law in framing their estimates of cost.

Rapid transit proper cannot be had on a surface road, and this, of course, applies to the trolley system. The United States Census gives 3,000 as the total mileage of electric roads in the United States in 1891, from which we may assume that in 1890 there were about 2,000 miles. On these, 135,000,000 passengers were carried. There are 289 miles of horse roads in New York, and they carry 486,000,000 passengers annually; whereas the New York elevated roads, with not over thirty miles, carry 400,000,000 passengers; showing that the elevated roads can handle vastly more pas-

sengers per mile of road than can any surface road, and, besides, they carry them much longer distances than are usually ridden on the surface roads.

No surface road can be expected to handle more passengers than does our Market Street cable road. It is not unusual there, at times of heavy traffic, to see three trains of three crowded cars each in one block at the same time, and under these circumstances these trains do not stop to take in passengers, and still the cable road cannot handle the traffic between say 5 and 6.30 P.M. An elevated railroad train of three cars would carry as many passengers as these nine cable cars; it makes fewer stops and is not subject to delay at junctions as are the cable cars at crossings of Seventh and Ninth Streets with Market Street.

The erection of a trolley system would be an effectual barrier to the erection of an elevated road. Market and Broad are the streets that would suffer least from the trolley system, but all would unite in insisting that Broad Street must be kept clear, and Market Street could have no trolley because it already has the cable, which spoils the street worse than the trolley would do.

During five or six years every wire put under ground was put there for the express purpose of showing that it could not be done. As soon as it came to be done by parties interested in having them there, it was seen that there was no difficulty about it.

On the new underground electric light system in London, 10,000 volts (a pressure which was ridiculed until two years ago) have been used for several months at the Deptford Station. There has been but one breakdown, and that was owing to a fire not incident to the operation of the road. Both sets of mains (four wires) were melted down, and operations were stopped for six hours.

I have heard complaints from Wilmington (Del.) people, that the noise of the trolley system there is so insufferable that they would prefer to go back to horse-power, in spite of the fact that the electric cars make in fifteen minutes a distance for which the horse cars required forty. The storage battery makes less noise than horse-power, and does not obstruct the street. The West End trolley system in Boston was recently stopped for two hours by an accident at the central station.

Any conduit is liable to the objection that it constitutes an open sewer. This difficulty is indeed mitigated to some extent by the fact that the slot renders the street unfit for travel by horses, but still the conduit remains a nuisance.

Mr. Herman S. Hering presented the following statistics obtained by students of Johns Hopkins University, in a comparison between the cable system and an electric road:

	Cable.	Electric.
Length of road	4½ miles	11 miles
Car-milcage during trial	640	550
Rated power of prime moyer	414 (engine I.H.P.)	520 (turbine Hyd. H.P.)
Per cent. of full load developed during trial	58	45
Mean H. P. developed	241	234
	Distribution of Power (in Per Cent.).	
Friction of prime mover	12.10 (engine)	40.6 (turbine)
Loss in transmission machinery of station	10.30	19.3
Loss from station to car axle	40.70	15.6
Power available at car axle	36.90	24.5
Power of prime mover	100.00	100.0

The turbine plant was running at a smaller percentage of full load and also had considerable friction in the gears. There were two turbines coupled to the same shaft.

The Secretary read a paper by a "Member of the Club," submitting that the Philadelphia system of compelling the street car companies to keep the streets in repair is a mistaken one, because it subjects the companies to a varying and indeterminate expense. It would be better to tax the companies with a certain percentage of their receipts. They would then know what to calculate upon. The writer is inclined to the view that the necessity for a system of mechanical power in the near future is overrated. Even if such a system were introduced, it would be impracticable to run cars upon roads like that on Spruce Street, for example, at a respectable rate of speed.

May 21, 1892.—Business Meeting.—Mr. James Christie, President, in the chair; about thirty persons present.

The Secretary read the following communication from the Board of Directors:—

"Regretting the necessity for the action, we respectfully recommend the acceptance of Mr. Trautwine's resignation of the Secretaryship."

On motion of Mr. Henry G. Morris, the resignation was accepted.

The Tellers of Election reported eighty legal votes cast, and the following gentlemen elected members: Active, Messrs. Edward H. Jenkins, B. Antrim Haldeman, William G. Hartranft and Clement B. Webster; Associate, Mr. J. Walter Douglas.

The Secretary read a description of the blue-prints submitted by Mr. C. S. Sims, Jr., and exhibited, descriptive of designs for an aerial watch-box for railroads.

Mr. Teile Henry Müller read a paper upon Evaporation by Multiple Effect. The paper was illustrated by a number of blue-prints, representing different forms of multiple-effect evaporators.

Mr. Henry G. Morris remarked that some of the old pans introduced throughout Louisiana and Cuba in 1847 and 1848, in conformity with the system described by Mr. Müller, were still in use side by side with much machinery of more modern construction, but operating on the same principle, and made not only in this country but in Germany and in France. The important question of cost depends largely upon getting the best form of evaporating surface in the cheapest form of envelope. Mr. Morris' aim in designing the evaporator proposed by him and described by Mr. Müller was to secure convenience of operation. With this end in view the tubes were so arranged as to be easily cleaned on the inside, while a large area was furnished for separation and for the reduction of entrainment. The design has not yet been carried out in practice. Mr. Morris sketched upon the blackboard an evaporator in which the heating surface consisted of coils of pipe, and a modification in which the coil was divided into convenient lengths so as to fill the space more completely and at the same time permit expansion and contraction without injury.

Mr. A. Falkenau, referring to the application of multiple-effect evaporation to the manufacture of ice as treated of in Mr. Müller's paper, described an ice machine in which evaporation took place under a vacuum, sulphuric acid being used to absorb the vapors. In some cases brine was employed, part of which was evaporated, the evaporation reducing the temperature of the remainder, which was circulated through the rooms to be cooled. In another case pure water was sprayed into the vacuum, and the cold caused by the rapid evaporation froze the spray, which built itself up in the shape of a cone of ice.

Although eight pounds of ice were produced per minute with the expenditure of half a horse-power, the operation is expensive, owing to the cost of re-concentrating the acid. As the power required is very small, the plant occupies but little room, and it would seem that on steamboats and railroads, where economy of space is of importance, the cost of re-concentration may not prove a serious item. Prof. Denton, of Stevens Institute, is making some tests of the apparatus with the determination of this question in view.

Mr. Müller described a system by which a part of the vapor from the first pan of the multiple-effect evaporator was compressed (and thus heated) by mechanical means and returned to the heating chamber. By this process the designers claim for their apparatus results which seemed to impress the speaker and other members present as involving a gain of more power than was put into the machine.

JUNE 4, 1892.—Regular Meeting.—Mr. James Christie, President, in the chair; thirty persons present.

The Secretary announced that at the last meeting of the Board of Directors, held May 31st, Prof. L. F. Rondinella was appointed Secretary of the Club, for the unexpired term of Mr. John C. Trautwine, Jr., resigned.

Mr. Henry G. Morris opened discussion on the location of the new Mint by suggesting as a site a part of South Sixth Street which is said to be infested with consumption, destroy the present buildings with fire if necessary, and replace them with buildings in every way suitable for the business of the mint. He thought it strange that it should be proposed to erect, in connection with the mint, a gas plant for heating purposes, and that the City could not supply gas for that purpose, and indeed that it would not supply gas to consumers for less than $1.50 per thousand, while a city like Cleveland was able to supply it at 80 cents per thousand. At the same time he considered it very doubtful whether a new mint were necessary.

Dr. Henry Leffman stated that we should hesitate to accept reports about diseased localities, for, from the results of his own investigations, he knew them to be generally unreliable. He thought, however, a better site could have been selected than the one fixed upon, from a commercial point of view, and that it would be a good thing to rebuild diseased districts of the city with better structures.

Mr. Henrik V. Loss started a discussion on the shearing of iron and steel by calling attention to the fact that while engineers were familiar with the action of other forces upon metals generally, they were yet much in doubt with regard to shearing. He considered hydraulic machinery the only available kind for accurate shearing tests, and described the results of a series of experiments that he had been making, but had not yet completed. From cards which he had taken he found that it requires more energy to cut iron than steel of the same dimensions, and less for both metals than is generally supposed.

Mr. John C. Trautwine, Jr., attributed the differences in the behavior of these two metals to the brittleness of steel compared with the tougher iron, and called attention to observations similar to those of Mr. Loss in a paper by Mr. F. H. Lewis, entitled Soft Steel in Bridges, which appeared in the January number of the Club's PROCEEDINGS.

Mr. A. Falkenau cited a case of a breaking pin in a compressing machine which persistently sheared off very suddenly, sometimes even under a strain less than its elastic limit.

Other members called attention to the facts that steel tanks holding water rusted much more quickly than iron ones used for the same purpose, and that pipes carrying oil seemed to rust more quickly than those carrying water.

Mr. Loss asked the opinion of members on the proper proportioning of valve-to cylinder-areas in high-pressure pumps. He considered flat better than cone-seated valves, and thought the valve-area should be about 30 per cent. of the area of the plunger.

Mr. Max Livingston called attention to an article in the Proceedings of the Society of Mechanical Engineers, by Professor Denton, describing a Worthington pump, the action of whose valves produced results which were then phenomenal, but have since been exceeded.

The Riedler Valve, a recent German invention, was described and favorably commented upon by Mr. Morris and others, and there was a general discussion upon other types.

JUNE 18, 1892.—Business Meeting.—President James Christie in the chair; 29 members and visitors present.

The Tellers reported the election of Messrs. George C. Thayer and William Elton Mott to Active Membership.

The resignations of Professor L. M. Haupt and Mr. Jesse Garrett were accepted.

Upon motion of Mr. John C. Trautwine, Jr., the Club appointed Mr. Jos. M. Wilson, to aid the Committee of the American Society of Civil Engineers by the suggestion of suitable persons to furnish papers for the meeting of the World's Congress Auxiliary of the Chicago Exposition.

A paper by Captain Smith S. Leach, on the Improvement of the Mississippi River, was presented and read by the Secretary. Mr. Trautwine explained that this paper was written, by request, to more fully explain the method of fixing the banks and confining the floods of this river, which had been illustrated by a series of photographs presented some time since by one of the members of the Club.

A communication from Mr. Robert L. Holliday, Active Member of the Club, describing a stone box culvert, built in 1832, south of Newcastle, upon the Delaware Division of the P. W. & B. R. R., was read, and a sample of two-inch white pine plank, which formed part of its foundation and had been under water for sixty years, was exhibited in connection therewith. The wood showed an excellent state of preservation, and excited much interest.

A section of the first rail used by the Camden and Amboy Railroad was presented by Mr. Rufus Hill, Master Mechanic of the Pavonia Shops. It is believed to be from the first lot of rails made in this country, and was laid November 12, 1831, at Bordentown, New Jersey. Designed by Mr. R. L. Stevens.

Mr. Wilfred Lewis, upon request, briefly described the recent trip of the American Society of Mechanical Engineers to San Francisco, and Mr. Washington Jones promised to assist him in preparing a more formal description to be presented to the Club in the fall.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

JANUARY 9, 1892.—President Wilfred Lewis in the chair. Present: Messrs. Hering, F. H. Lewis, Spangler and Townsend, also the Treasurer and the Secretary.

The Annual Report of the Board of Directors was considered and a form decided upon.

The action of the House Committee, in letting the Club Rooms to the Philadelphia Yacht Club for the evening of 12th inst., was approved, and it was ordered that the standing charge for such use should be $10 per evening.

JANUARY 16, 1892.—President Wilfred Lewis in the chair. Present: Messrs. Rudolph Hering, M. R. Mucklé, Jr., P. G. Salom and David Townsend, also the Treasurer and the Secretary.

The Secretary was authorized to engage clerical assistance for one month at an expense not to exceed $50.

The Secretary was directed to prepare and to submit to the Board at its next meeting a plan for the sale of back numbers of the Proceedings.

The Secretary announced the death of Edward Nichols, Active Member of the Club, and President of the Brooks Locomotive Works, Dunkirk, New York.

The draft of the Annual Report of the Board was read, amended and finally approved.

The Secretary read a letter from A. J. Rudderow, Esq., announcing that the Club charter had been signed by the Court.

The Secretary presented for Mr. Richard B. Osborne, a framed lithographic view of the river front of Philadelphia in 1761, and was directed to express the thanks of the Board for the same.

JANUARY 23, 1892.—Present: President James Christie, Vice-Presidents F. H. Lewis and P. G. Salom, and Directors Geo. V. Cresson, Strickland L. Kneass, Wilfred Lewis, H. W. Spangler and David Townsend, Mr. T. Carpenter Smith, Treasurer, A. J. Rudderow, Esq., and the Secretary.

The Secretary was directed to draw lots to determine which of the Vice-Presidents and which of the Directors should serve for two years. The result of the drawing was that Mr. F. H. Lewis, Vice-President, and Messrs. Kneass, Spangler and Townsend, Directors, were to serve for two years.

The Board took up the question of the revision of the Constitution and By-Laws.

It was unanimously ordered that the Chair appoint a Committee of the Board to consider the question of amending the Constitution and By-Laws in regard to the provision for Honorary Membership and in other respects. The President appointed Messrs. Salom, Spangler and F. H. Lewis on this Committee.

The Secretary read a letter to the Board with suggestions respecting the sale of back numbers of the Proceedings, securing additional copies of certain numbers, measures for increasing the subscription list, and the fixing of a price on extra copies of the Proceedings to those contributing papers or discussion. The letter was referred to the Publication Committee with power to act.

The Secretary submitted a proposed form of letter to certain members of the Club soliciting subscriptions, which was referred to the Finance Committee with power to act.

The Secretary submitted an abstract of the Annual Report of the Board of Directors which he proposed sending out with the Annual Bills, to which no objection was made.

On motion it was declared to be the understanding of the Board as to the meaning of Article IV, Section 5, of the By-Laws, that the three consecutive and regularly called meetings of the Board there referred to are intended to mean three consecutive monthly meetings, regularly called.

The importance of having itemized accounts from the Treasurer showing the annual expenditures of the several Committees was urged. The Treasurer replied that it is his intention to furnish such an account of the present year's operations.

The matter of soliciting exchanges for the Proceedings was referred to the Library Committee.

February 20, 1892.—Present: Messrs. Codman, Kneass, W. Lewis, Spangler, Townsend, and Treasurer Smith.

In the absence of the President and Secretary by reason of illness, Mr. Townsend was called to the Chair, and Mr. Lewis acted as Secretary *pro tem.*

It was ordered that the Secretary's clerical assistance be extended six weeks.

Prof. Spangler was appointed to act as Secretary during the temporary absence of Mr. Trautwine on account of illness.

The Publication Committee was empowered to have printed a form announcing the necessary times and conditions of payment of dues and initiation fee as set forth in the By-Laws.

The Treasurer read an approximate statement of his accounts.

March 19, 1892.—President James Christie in the chair. Present: Messrs. Codman, Cresson, F. H. Lewis, Wilfred Lewis, Kneass, Spangler, Townsend, and Treasurer T. C. Smith.

The Secretary presented a letter from Mr. John W. Cloud, the Club's representative in Chicago, on the subject of the Engineering Congress, and the Secretary was instructed to communicate with the secretaries of the larger societies taking part in the Engineering Headquarters, and ask what action had been taken in their societies with relation to the Congress.

The Secretary also presented a letter from the Cassier Magazine Company, relating to an article to appear in that magazine on the subject of the Engineers' Club of Philadelphia, and the Secretary was directed to furnish such matter as would be necessary to make the article a satisfactory one, the understanding being, however, that the Club was to be put to no expense.

A letter was presented from Mr. Trautwine, calling attention to the necessity of providing for further clerical assistance, and on motion of Mr. Townsend the present arrangement was ordered to be continued until April 30th.

The Treasurer presented a partial report of the financial affairs of the Club, and the Finance Committee was requested to furnish the Board at the meeting to be held as soon as the report was ready, a statement of the probable expenses and income for the year.

The Publication Committee called the attention of the Library Committee to the apparent large list of exchanges, and asked that in view of the cost of our Proceedings, all the names on this list from which we are not getting full value, should be expunged.

The Library Committee acknowledged the gift of ten volumes of the *Franklin Institute Journal* from Mr. Chas. T. Thompson.

The Committee on Revising the Constitution was increased to five members, and the Committee was directed to select its own chairman, and requested to report promptly to the Board.

The President appointed Messrs. Townsend and Kneass the additional members.

The Membership Committee reported that it had a number of applications for membership in its hands, and also a number of resignations, and asked that the next meeting of the Club be made a Business Meeting, and it was so ordered.

April 9, 1892.—President James Christie in the chair. Present: Messrs. Codman, Cresson, Kneass, Salom, Spangler and Townsend.

The Finance Committee presented a statement showing the income and outgo for one year, and also the probable condition of affairs of the Club at the end of the present fiscal year.

The House Committee presented an estimate as to the cost of making the Secretary's office secure from intrusion by unauthorized persons, and on motion it was ordered that it be attended to immediately.

The Membership Committee presented the resignations of Messrs. A. S. Coffin, Frank Lyman, A. Millet, J. H. Skinker, W. S. Chaplin, S. B. Whiting, J. B. Nau, R. E. Pettit and G. R. Henderson, and it was ordered that these be reported to the Club at the next Business Meeting, with the recommendation that they be accepted.

April 16, 1892.—President James Christie in the chair. Present: Messrs. Townsend, Spangler, Kneass, Wilfred Lewis and Codman, also the Secretary.

Mr. Spangler announced that following the instructions of the Board, he had communicated, as Secretary *pro tem.*, with the American Societies of Civil Engineers and Mechanical Engineers, and the American Institutes of Mining Engineers and Electrical Engineers, with reference to their participation in the establishment of an Engineering Headquarters and Congress at the Chicago Exposition, and reported the results to the Board.

An informal verbal report was made from the Committee on Revision of the Constitution, outlining the changes now under consideration.

The Finance Committee was requested to make a report to the Board as to the best means of curtailing the expenses of the Club.

The Secretary announced his intention of presenting his resignation of office at the evening meeting of the Club, for action at the next Business Meeting, and asked an early appointment of his successor.

May 9, 1892.—President James Christie in the chair. Present: Messrs. Cresson, Kneass, Salom and Townsend, also the Treasurer and the Secretary.

The Secretary presented the following communication:

From Mr. Octave Chanute, President General Committee of Engineering Societies, Columbian Exposition, Chicago, enclosing copy of letter sent by the Executive Committee to Mr. John W. Cloud, the Club's representative in Chicago, notifying him of a meeting of delegates comprising the General Committee of Engineering Societies, at Chicago, on May 4.

The Secretary reported that several members elected in January, February and April, of the present year, had not paid their initiation fees, and signed the Constitution and By-Laws, and he was directed to communicate with them in the premises.

The Secretary stated that, as suggested at the last Board Meeting, he had communicated with the Philadelphia Postmaster in the matter of pound rates for our Proceedings, but had been referred by the Postmaster to the Superintendent of Mails, who had already been called upon in the premises.

On motion of Mr. David Townsend, the employment of the stenographer was continued until the end of May.

The Secretary read a report from the Finance Committee in response to the request of the Board for suggestions as to curtailment of expenses. The Committee believes it would be inadvisable to increase the annual dues, but urges a determined and organized effort to increase the number of members, efforts to increase the advertising list in the Proceedings and the number of subscribers for the Proceedings and the renting of the three fourth-story rooms. The Committee advises an amendment of the By-Laws dispensing with the two June meetings. The Committee recommends a private subscription to pay off extraordinary indebtedness.

As the time for opening the Club Meeting had more than passed, no action was taken upon the report.

The House Committee was authorized to insure the furniture and books belonging to the Club.

May 21, 1892.—President James Christie in the chair. Present: Messrs. F. H. Lewis and Salom, Vice-Presidents; and Messrs. Codman, Cresson, Kneass, Spangler and Townsend, Directors; and the Secretary.

The Secretary read the report of the Finance Committee upon means for curtailment of expenses, which was presented at the meeting of the Board on May 7, and the recommendations of the report were then taken up seriatim.

The suggestion for a determined and organized effort to increase the membership, was referred to Mr. Townsend with power to act.

The matter of selecting popular subjects for discussion at one meeting a month, and having the same fully reported in the daily papers, was referred to the Committee on Information and Entertainment.

The matter of increasing the advertising list in the Proceedings and extending the list of subscriptions, was referred to the Publication Committee with power to act.

The matter of renting the three fourth-story rooms was referred to the House Committee with power to act.

Each member of the Board was constituted a Committee of one to solicit special subscriptions toward the paying off of the extraordinary indebtedness of the Club, and to report at the Special Meeting on Saturday next.

The Board recommended to the Club the acceptance of the Secretary's resignation, and to express the regrets of the Board in the premises.

The Secretary presented, on behalf of the Treasurer, a statement of the balance of cash in hand, with a statement of the amounts owing by the Club, including a number of bills approved by the Finance Committee, and requesting instructions from that Committee as to which of these bills should be preferred in order of payment.

The Secretary presented a diagram showing the attendance at meetings and the additions to the membership, from the organization of the Club, and indicating a marked increase in both items during the past year; also letters from the Secretary of the Athletic Club of the Schuylkill Navy, stating that the increase in members' dues by that club had proved a financial success.

It was ordered that the services of the stenographer be retained for the month of June.

MAY 28, 1892.—Present: President James Christie, Directors Strickland L. Kneass and H. W. Spangler, and the Secretary.

No quorum.

The Secretary presented a communication from Mr. David Townsend, submitting a form of circular to be sent to the members of the Club, enclosing blank forms of application for membership, and soliciting special efforts to induce suitable persons to become members. A form of postal card asking for additional blank forms, and a form of reminder to the members, to be sent out with subsequent notice of meeting, were also submitted.

The Secretary presented invitations from the American Society of Civil Engineers, to attend the Annual Convention of the Society at Old Point Comfort, Virginia, beginning June 8, 1892, and to name a member of the Club to aid a Committee of the Society in the selections of persons to furnish papers for the Civil Engineering Section of the Congress to be held at the Chicago Exposition in 1893.

The Secretary submitted a report from the Treasurer, showing balance of cash in hand, $422.73.

MAY 31, 1892.—Present: President James Christie, Vice-President Salom, Directors Codman, Kneass and Spangler, and the Secretary.

The recommendations of Mr. Townsend, submitted at the last meeting, respecting the sending of a circular to the members of the Club, urging special efforts to increase the membership, were adopted, and it was ordered that they be carried out.

On motion of Mr. Strickland L. Kneass, Prof. L. F. Rondinella was appointed Secretary for the unexpired term of Mr. Trautwine.

The following subscriptions to the special fund for reducing the extraordinary indebtedness of the Club, were reported: A. Falkenau, $10; James Christie, $20; Henry G. Morris, $10; Strickland L. Kneass, $10; P. G. Salom, $10; and H. W. Spangler, $10.

The Secretary was directed to notify the Treasurer that these sums which had been contributed were for a special purpose, and to request him to set the same aside and to hold them subject to the order of the Finance Committee.

The recommendation of the Library Committee for the purchase of "The History of Iron in All Ages," by James M. Swank, was presented, but no action was taken.

The Finance Committee was requested to suggest a system of keeping the accounts of the Club, and to instruct the Treasurer and the Secretary accordingly.

The Secretary was directed to communicate with Prof. L. M. Haupt and ascertain whether he will accept an appointment by the Club to aid the Committee of the American Society of Civil Engineers in charge of the Civil Engineering Branch of the World's Congress at the Chicago Exposition, by the suggestion of persons who are in position to furnish papers for that purpose.

JUNE 18, 1892.—Present: President James Christie, Vice-Presidents F. H. Lewis and P. G. Salom and Directors H. W. Spangler, Wilfred Lewis and David Townsend, and the Secretary.

The Publication Committee reported that they proposed to print 200 extra copies of the next issue of the Club Proceedings, to use in soliciting new advertisements.

The Finance Committee presented a statement of the financial condition of the Club, and submitted an informal report from the Treasurer.

The Secretary was directed to send out monthly statements to all members in arrears, as advised by the Treasurer's reports.

A letter from Professor Haupt, declining appointment by the Club to aid the Committee of the American Society of Civil Engineers by the suggestion of persons to furnish papers for the World's Congress Auxiliary of the Chicago Exposition, was presented and the matter was referred to the Club for action.

Mr. F. H. Lewis presented the following, which was adopted:

Resolved, That it is the sense of the Board that it would be a great advantage to have all the Club's records at the Club House, and readily available for the use of the Board, and that the Treasurer is therefore requested to utilize the clerk of the Club for keeping his books and accounts, with intent as above, and is further requested to effect this arrangement prior to July 1st, so that the Board can adjust the Club's finances for the summer recess.

Upon motion of Mr. Townsend, the stenographer was engaged at her present salary to the end of the year.

CONTRIBUTIONS TO THE LIBRARY.

From October 31, 1891, to June 30, 1892.

From MR. A. A. McLEOD.

The Improvement of the Schuylkill Water Supply of the City of Philadelphia.

From MALVERD A. HOWE, C.E.

Some Experiments to Determine the Strength of American Vitrified Sewer Pipe.

From MR. J. F. LEBARON.

Florida, The Underground Wealth and Prehistoric Wonders of Polk and De Soto Counties.

The Phosphate Fields of Florida.

From BOARD ON TESTING IRON, STEEL AND OTHER METALS.

Report of Board, Vols. I. to II., 1891.

Tests of Metals, etc., 1883-1889. 1886, Parts 1 and 2.

From BUREAU OF STATISTICS, Washington, D. C.

Special Consular Reports. Streets and Highways in Foreign Countries, 1891.

From U. S. GEOLOGICAL SURVEY, Washington, D. C.

Bulletins, Nos. 62, 65 and 67–81, inclusive.

Report, 1888–89.

From MR. C. G. HILDRETH, Associate Member of the Club.

Official Reports of Various Duty Trials of the Gaskill Pumping Engine.—The Holly Manufacturing Company, Lockport, N. Y.

From MR. CHAS. P. F. BAILLAIRGE, City Engineer of Quebec.

English Homonyms.

Homonyms Français.

Papers read before the Royal Society of Canada, 1882 and 1883.

General Application of the Prismoidal Formula.

Hints to Geometers for a new edition of Euclid.

Simplified Solution of Problems in Hydrography and Parting off Land.

The Areas of Spherical Triangles and Polygons to any Radius or Diameter.

Biographical Sketch of Mr. Baillairge.

The Stereometrican.

The Aqueduct, Quebec, September, 1885.

Quebec, Passi, Present, Futur.

A Particular Case of Hydraulic Ram or Water Hammer.

An Attempt to Deduce the Pressure per Square Inch under which a Steam Boiler Explodes from the Effects Produced by the Explosion.

A Paper Relating to the Solution of the Problem of Determining the Height to which a Missile Attained, which, in Descending again to the Level from which it was Projected, produced a given or known result.

From MR. JOHN BIRKINBINE, Active Member of the Club.

The Development of the Pig Iron Manufacture in the United States.

Reprint from Journal of Franklin Institute, November and December, 1891.

From MR. C. W. RAYMOND.

Annual Reports upon the Improvement of the Delaware and Schuylkill Rivers, 1891.

From U. S. NAVY, Washington, D. C.

Annual Report of the Chief of the Bureau of Construction and Repair to the Secretary of the Navy for the fiscal year ending June 30, 1891.

From HISTORICAL AND SCIENTIFIC SOCIETY OF MANITOBA.

Surface Geology of the Red River and Assiniboin Valleys.

Annual Report.

The first Recorder of Rupert's Land.

From HON. J. M. RUSK.

Album of Agricultural Graphics.

Album of Agricultural Statistics of the United States.

From MR. GEORGE S. RICE.

Report on the Transportation of Passengers in and around the Cities of Europe.

Report of same by John E. Fitzgerald.

Report of the Rapid Transit Commission to the Massachusetts Legislature, April 5, 1892.

From ASSOCIATION OF DOMINION LAND SURVEYORS.

Report of Proceedings at Eighth Annual Meeting.

From PROF. L. M. HAUPT, Active Member of the Club.

The Port of Philadelphia.

From MR. JAMES CHRISTIE, Active Member of the Club.

Die Strassenbrücke über die Norder-Elbe bei Hamburg.

From INSTITUTION OF CIVIL ENGINEERS, London.

Downes—Practical Astronomy as applied to Land Surveying.

Dymond—Electric Lighting at Tamworth, New South Wales.

Joyce—Queensland Water Supply.

Walker—Four-screw Hopper Dredge.

Airy—Weighing Machines.

Bamber and Cary—Portland Cement; Smith—Portland Cement Concrete.

Beare—Building Stones of Great Britain.

Fox—Hawarden Bridge.

Gill—Sale of Water by Meter in Berlin.

Manby—Aranco Railway and Bio-Bio Bridge.

Mathews—Southampton Water Works and Softening Plant.

Michaelis—Behavior of Portland Cement in Sea-Water.

Rochemont—Portland Cements at Havre.

Bamber—Transverse Steel Sleepers.

Bruce—Rosario Water Works, Argentine Republic.

Wordingham—Meters for Electrical Energy.

Abstracts of Papers in Foreign Transactions and Periodicals.

From ENGINEERING NEWS.

Manual of American Water Works, 1890–91.

From MR. F. R. FORD, Active Member of the Club.

The Short Electric Railway Company.

From THE NICARAGUA CANAL CONSTRUCTION COMPANY.

The Inter-Oceanic Canal of Nicaragua.

From MESSRS. THOS. COOK AND SON.

The Business of Travel.

From MISSOURI GEOLOGICAL SURVEY.

Preliminary Report on Coal.

From MR. RICHARDSON GLOVER.

Telegraphic Determination of Longitudes in Mexico, Central America, the West Indies, and on the North Coast of South America.

From MR. E. L. CORTHELL, Active Member of the Club.

Corthell on an Enlarged Water-way.

From GEOLOGICAL SURVEY OF PENNSYLVANIA.

S. C. Field Atlas, Part 4.

W. M. C. Field Atlas, Part 3.

N. C. Field Atlas, Part 6.

C. 5, F. 3, N. and County Geological Maps.

Summary Final Report, 1892, Vol. I., Laurentian Cambrian, L., Silurian.

Atlas Southern Anthracite Field, Parts 4, 5, and 6.

From COMMISSIONER OF EDUCATION, Washington, D. C.

Report for 1888-89.

History of Higher Education in Massachusetts.

History of Higher Education in Ohio.

History of Higher Education in Michigan.

Fourth International Prison Congress, St. Petersburg, Russia.

From CHIEF OF ENGINEERS, U. S. A.

Annual Report for 1891.

From MR. CHAS. T. THOMPSON, Active Member of the Club.

Journal of Franklin Institute, 1867–1876, inclusive.

From MR. WM. BARCLAY PARSONS.

Report of Rapid Transit Railroad Commissioners in and for the City of New York.

From MR. HARVEY LINTON, Active Member of the Club.

Annual Report of the City Engineer, City of Altoona.

From U. S. COAST AND GEODETIC SURVEY.

Report for 1890.

From MR. GEO. A. BULLOCK, Active Member of the Club.

Annual Report of the Bureau of Highways for the year 1891.

From INTERSTATE COMMERCE COMMISSION.

Report for 1891.

From CARNEGIE, PHIPPS AND COMPANY.

Pocket Companion, 1892.

From GEOLOGICAL SURVEY OF NEW JERSEY.

Annual Report of State Geologist for 1891.

From HON. B. E. FERNOW.

Timber Physics, Part 1. Preliminary Report.

From SMITHSONIAN INSTITUTION.

Report, 1890.

From MR. M. CHIZUKA, Tokio, Japan.

The Locomotive.

From MR. JOHN KENNEDY.

Report of Harbor Commissioners of Montreal, 1891.

From MR. RUDOLPH HERING, Active Member of the Club.

Report upon the Sewerage of the District of Columbia.